The WELDING JOURNAL

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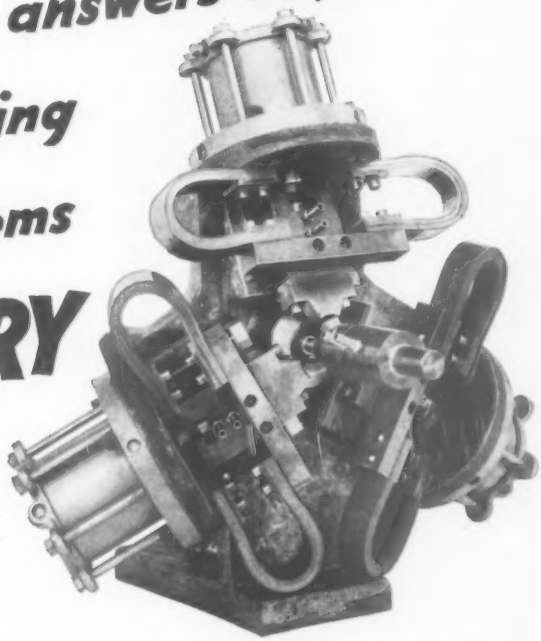

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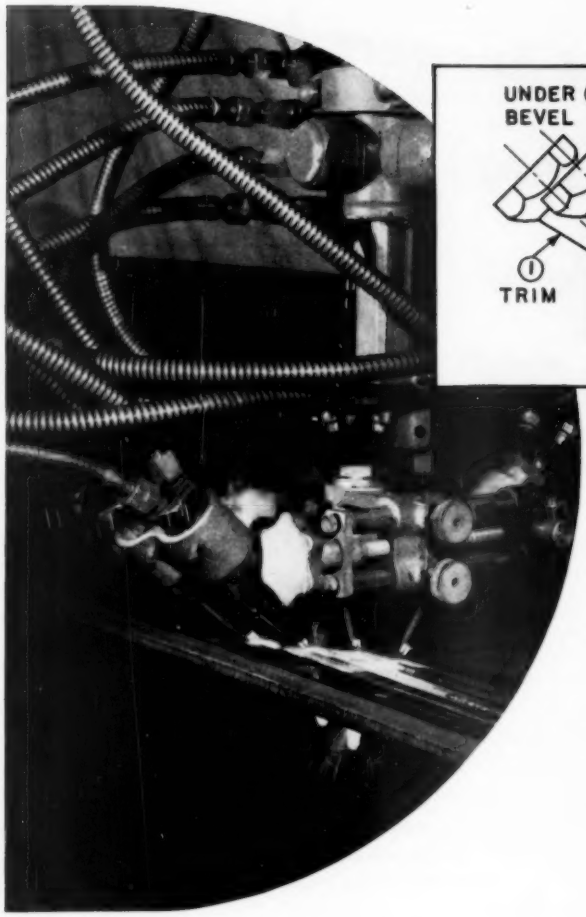

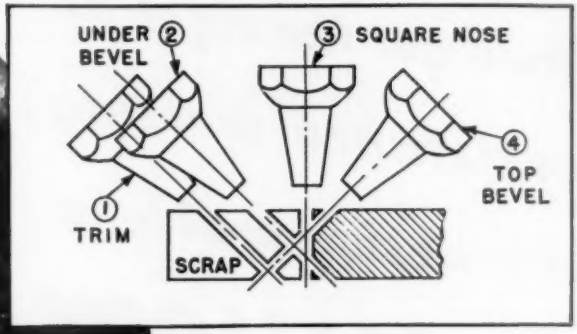

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The WELDING JOURNAL

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Fig. 1 Long heat exchanger

Welding Heat Exchangers for the Chemical Industry

A pictorial presentation of different types of heat exchangers and fabrication procedures for their manufacture

by John W. Mortimer

A HEAT exchanger is a piece of equipment that permits heat to flow or "exchange" from one mass to another. The Mechanical Engineer defines the heat exchanger in terms of power equipment. The Chemical Engineer defines them as a means of heating or cooling liquids, pastes and even dry pellets in order to accomplish a change in the material.

There are long units (see Fig. 1) with small diameter, as well as short units with large diameters (Fig. 2). There are exchangers with helical coils and some with zig-zag arrangements (Figs. 3 and 4). The characteristics of the material to heat or cool control the design of the exchanger.

A very common example is the storage hot water heater for homes as well as office buildings (Fig. 5). Usually there is a copper coil exposed to a gas flame or the coil is submerged in the water with steam in the coil as the heating medium (Fig. 6). The same operation or function is accomplished in the instantaneous heater by having the coil equivalent in size or capacity to the water (Fig. 7), thus, the water is heated as fast as it is used without any storage whatsoever.

Another type is the "vat" or "open" type with coils around the walls on the bottom, or completely filled with coils. Another popular open type would be chillers, as used in cooling milk over a cascade of coils.

The closed type exchangers are likened to a pressure vessel with a separate pressure chamber enclosed within it. Accomplishing this particular type of construc-

John W. Mortimer is Professional Welding Engineer for the Whitlock Manufacturing Co., Hartford, Conn.

Paper was presented at the Thirty-Second Annual Meeting, AWS, Detroit, Mich., week of Oct. 15, 1951.

tion has produced several unique designs as well as patented types of construction.

Like all specialized manufacturing the heat exchanger engineers have formed an association in order that standards may be made. The Tubular Exchanger Manufacturers Assn. was formed for just such a pur-

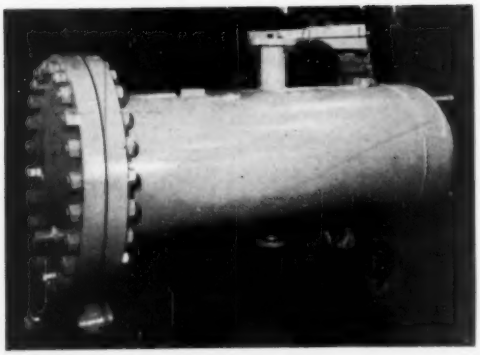

Fig. 2 Short heat exchanger

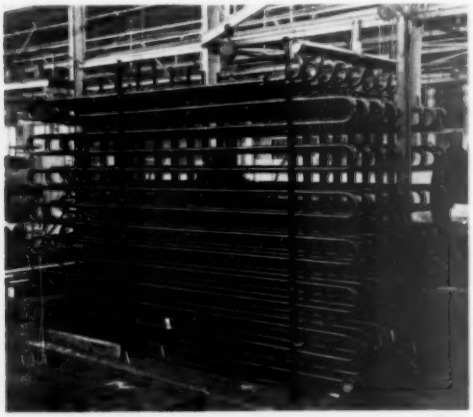

Fig. 4 Zig-zag coil bank, steel pipe

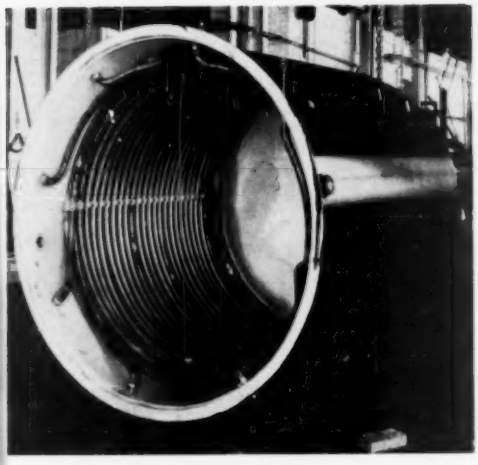

Fig. 3 Helical coil installation, copper coil in steel tank

Fig. 5 Hot water storage heater, steel shell with copper tubes and cast-iron steam head

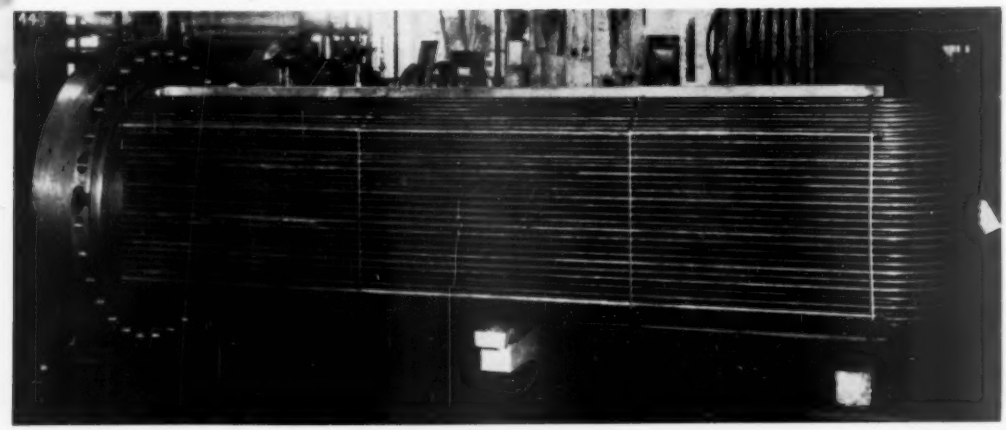

Fig. 6 Tube element, copper tubes with steel tube sheet

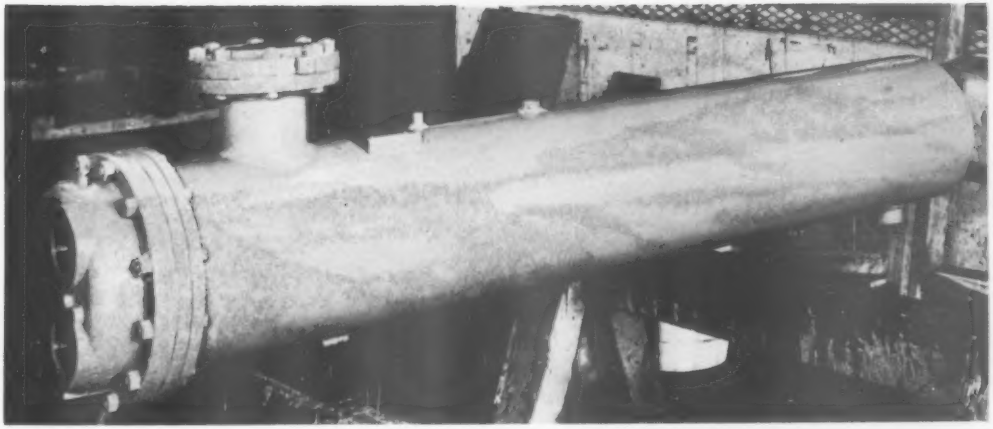

Fig. 7 Instantaneous heater—steel shell, copper tubes and cast-iron steam head

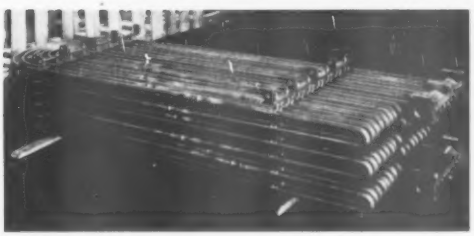

Fig. 8 Preheater—copper tubes and bronze headers

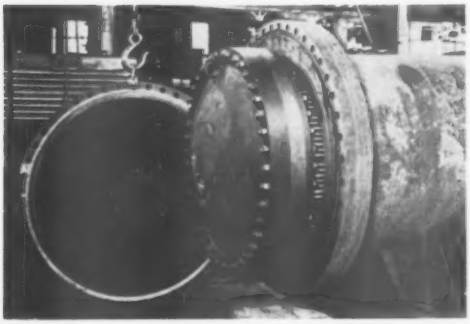

Fig. 9 Floating head with rear shell cover removed to show split ring construction

Fig. 10 Outside packed floating head

pose and now there are standards for structural and thermal design as well as types for all service conditions. The industries using this equipment have benefited as much if not more than the manufacturers.

The straight tube type with fixed and floating tube sheets is very common (Fig. 9). If it is necessary to keep the fluid flow close around the tubes with little clearance then the split ring floating head is used. Sometimes it is necessary to have the tube ends accessible and this is done by using the outside packed floating head (Fig. 10).

In exchangers that operate with a small temperature differential where tube expansion is not severe, the tube sheets may be welded to the shell together with the distributing chambers. This type is very economical to build, but is limited to type of service. Fuel oil heaters for power boilers are very often designed this way.

Because two tube sheets offer twice as many joints to keep tight and maintain, some designers have specialized in the "return tube" type exchanger (Fig. 11). This design cannot be used, however, if the material in the tubes has a fouling nature, because the tubes cannot be readily cleaned.

In some fluids when converted into vapors or having noncondensable vapors which must be carried off, the outside packed floating tube sheet design is modified to take off these excess vapors by locating a vapor outlet with a protecting liquid funnel.

High-pressure requirements at times control the type of design. The "bayonet" type has become popular because small diameters and heavy wall pipe can be used. The double-pipe design is also used for extreme high pressures (Fig. 12).

There are heat-transfer problems that arise in the Chemical Industry that bring together liquids and vapor injected into the flow stream. This type of unit usually incorporates a double distributing chamber with the bayonet design in one to distribute the material through the second chamber and on into the tubes.

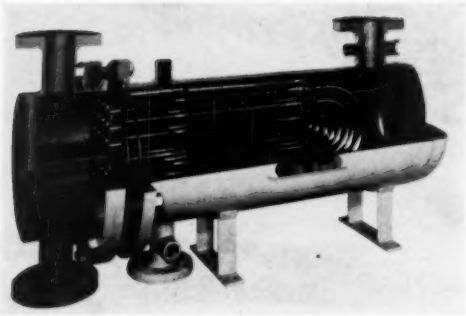

Fig. 11 Return tube "Type R" heat exchanger, cut away to show construction and fit of parts. Shell is made of steel. Tubes are stainless, Type 304, tube sheet and head are stainless, Type 304

In some heat exchange processes the tubular construction does not meet the requirement of the fluids or materials to be handled. The oil refining industry has such a problem in driving off, or separating, the heavy from the light hydrocarbons. The bubble tower design permits several different vaporizing temperatures to operate within one pressure vessel and separate the vapors of each temperature (Fig. 13).

These few basic types are used to meet the service demands as well as the fabricators' ease of manufacture. The size and shape of these units are controlled by the volume and temperature of the material to be handled. A small volume with a large temperature differential causes the design to be small in diameter and very long. A large volume with a small temperature change makes the unit short and large in diameter. Of course, viscosity, weight, velocity and pressure all take part in controlling the design of the exchanger.

The thermal design of the unit makes it possible to arrive at the size and shape. The temperature range and operating pressure are the controlling features for the thickness of the shell and tubes as well as the flange design.

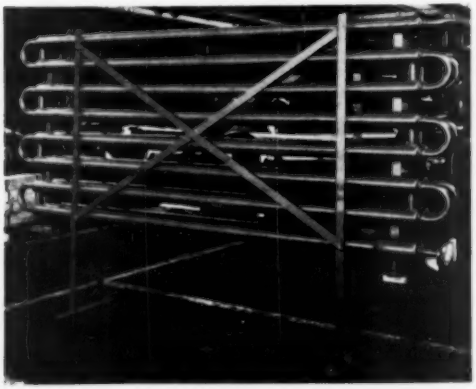

Fig. 12 Double pipe bank, shows how very long heat exchanger can be broken down into several units in series

The service or operating conditions such as temperature, pressure and corrosion control the type of material of which the vessel will be constructed. Probably the corrosion characteristics have more influence on just which material is used. The austenitic (304–347), martensitic (502) and ferritic (430) stainless steels all fit types of corrosive media. The nonferrous metals and alloy fit still another service. Copper and copper alloys, nickel and nickel alloys, aluminum and aluminum alloys are becoming more popular every year.

With the type of exchanger known and the materials of construction chosen the Welding Engineer works out the details of fusing the different parts together. The types of joints, the procedure control, together with the types of welding, are all coordinated to make a practical exchanger for the detailer to draw up.

While the Chemical and Mechanical Engineer designed the functional heat exchanger and the Metallurgical Engineer made the material to withstand the heat and corrosion, it took the Welding Engineer to make the design practicable.

The fabricating shop cuts plates, drills tube sheets, rolls up shells, forges flanges and welds similar and dissimilar metals together. A complex pressure vessel such as exchangers must have structural strength tests as well as test for leaks. The testing of special units has developed into a highly technical and yet very practical setup. The most common test is the hydro-

Fig. 13 Bubble tower section, showing tray construction, section made of copper with steel back-up flanges

Fig. 14 Bubble tower assembly ready for hydrostatic test

static test. This test usually is done in two steps. First, the pressure is raised to one and one-quarter to one and one-half times the design pressure, and is hammered to check for strength and impact. Second, the pressure is then increased to one and one-half or two times the design pressure and checked for leaks. Air testing with soap is the next most popular. This test is considered more sensitive than the hydro test. Air testing with the unit under water is used especially with coils. Some units, such as clad metals, are tested with light oils. This oil test permits a check on the bonding of the clad material by retaining oil in the surface imperfections. A still more sensitive test is with ammonia gas pressurized in the shell and checked for leaks with sulphur dioxide. This is the test used in most refrigeration units. The most sensitive test used is the vacuum test. It is possible to draw vacuums on any size unit down to within one-half a micron of mercury pressure. A micron is one-thousandth of a millimeter, or 0.00002 in. or $^{2}/_{100,000}$ in. In this test an electronic leak detector is used to find leaks.

Retracing the fabrication details to the welding of the metals, we find most exchangers are built of mild steel with copper tubes. Two methods are used to weld these units, namely, hand metallic arc welding and automatic metallic arc welding. A great many units are built with cast-iron parts in the water circuit and the tube sheets are usually some nonferrous material such as naval bronze or silicon bronze. Stainless steels such as the chrome-nickel series are probably the next most popular for most types of corrosion service. These chrome-nickel stainless steels are alloyed with molybdenum, titanium and columbium to give resistance to corrosion in the as-welded condition. The service range of these metals is also increased by alloying; for instance, the temperature operating range is from -300 to $+1500°$ F.

The martensitic stainless steels or the low chrome group are very good for high temperatures and they retain their strength at these elevated temperatures. These chrome stainless steels are difficult to weld and require complete procedure control and postheat treatment.

The ferritic stainless steels or the high chrome group are used for high-temperature service and because of their high creep strength. Only a few heat exchangers are built in this group. Welding these steels is very difficult and requires special control of the welding procedure.

Nonferrous metals of the copper, nickel and aluminum groups are used in corrosive service with temperature and pressure limitations. These metals are being exploited more and more because the new types of welding have brought them under complete control. Most of these metals can be metallic arc welded but for pressure-tight, strong welds it is necessary to use inert arc procedures. The electrometallurgical characteristics of these nonferrous metals have poised some of the most baffling problems. Many inert arc procedures have been worked out to solve these problems. The most common is the tungsten electrode with argon gas and d.-c. current with straight polarity. Many nonferrous metals work better with this same procedure but using helium gas for the shield. A few procedures have been worked out using a carbon electrode. A.-C. current with superimposing high-frequency current is used to weld a few difficult metals such as aluminum. This type of A.-C. welding circuit is very good on many metals but is rather expensive in the initial cost of equipment.

Heavy wall thickness of material is no barrier to the inert arc today, even with the high heat losses encountered with copper and aluminum. Both of these metals have been welded up to 3-in. thick plate and have proved sound by X-raying and as strong as the base plate.

Low-temperature service makes such demands on the Metallurgist and Welding Engineer that even the imagination must reach out. Equipment-handling liquids at $-350°$ F. must retain their physical characteristics the same as at room temperature. There are metals for this service, but to weld them and make the weld as strong and ductile as the base material is

the major problem. The working pressure and corrosion characteristics usually control which metal is used. Silicon bronze is very good at these extremely low temperatures. If the pressure is high then it becomes more economical to use austenitic stainless steels because they are much stronger and also retain excellent impact and ductile properties at low temperatures. The stainless steels run one and one-half times copper in strength and five times that of aluminum. When thickness becomes important it becomes logical to use the strongest material. The same logic is used at high temperatures with allowable working stresses. Sometimes because of heat-transfer characteristics a weaker material must be used; then, the design must be the controlling factor. Small diameter double-pipe units answer this problem best and it is very easy to have several banks in series—parallel arrangements for large capacities. The welding is also easily handled because almost all joints can be made with butt welds and fillets. If it is necessary to have two different metals for inner and outer tubes the combination weld always can be made as fillet which is the easiest weld to make.

Service conditions requiring special surface finishes make the treatment of the weld overlay most important. Food processing specifies the surface necessary; flow conditions also control surface finish requirements, and where impact stress becomes important surface imperfections cannot be tolerated. Equipment falling in this classification requires grinding and polishing of welds to contour the surfaces. The design of these welds is very important because welds made out of the flat position invariably have slight undercuts which must be smoothed out (Fig. 15). Special testing falls into the nondestructive classification. X-raying all welds, magnetic partial testing, black-light testing and surface profilemeter testing have all been used and in some cases to extremes to assure smooth contour of joining surfaces.

Many materials being used for these special units have been subjected to "ultrasonic testing." This type of testing not only assures the fabricator of sound material but also that the material is homogeneous in grain structure.

Completed exchangers often are tested for leaks by electronic leak detectors. Some of these tests involve very high vacuums while others work on pressure testing with sensitized gases for the telltale leak. Electronic leak detectors have proved to be the most sensitive test employed to date. These tests will also gage to size and rate of leak. This information may be used on a comparative basis with the actual liquids or gases to be used in the units.

Fig. 15 Special weld finish, low alloy steel welds ground for contour blending into shell plate

Systems for handling hot corrosive acids become very special, because of the few alloys able to withstand the action. The Hastelloy metals are metallurgical prizes, but offer some of the most difficult welding problems. Their shrinkage coefficients are very high, and correspondingly, the shrinkage stress can exceed the ultimate strength. This fact makes them crack sensitive and their alloys are gas sensitive, which makes them susceptible to porosity. Even after a good welding procedure is developed the heat treatment necessary to restore ductility and corrosion resistance is up to 2200° F. and water quenched. This would not seem too difficult only for the fact that the material melts at 2350° F.; thus furnace control becomes the most important factor in finishing the assembly. Welded heat exchangers of this type are products of coordination between Chemical, Metallurgical and Welding Engineers. The Chemical Engineer makes the demands on the Metallurgists for the right material and finally the Welding Engineer develops the proper procedure to fuse these alloys into one working unit.

Almost all these metals used in the manufacture of heat exchangers can be welded to produce a fused seam that is as good if not better than the base material. These metals are not only weldable, but in almost every instance they can be welded or brazed to each other in a strong, ductile joint. Aluminum does not follow this general pattern; while it has excellent welding characteristics, it still is not fusible to other metals in making bimetal seams.

As the Chemical Industries move forward, new demands will be made on the designer of equipment. He will in turn make new demands on the Metallurgist and so on to the Welding Engineer. With teamwork like this, we will all benefit and learn with each new process.

CORRECTION

In the article entitled, "Welding of High Heat-Resistant Materials," by J. L. Solomon in the March 1952 issue of the JOURNAL, Table 1, p. 234 the chemical analysis of Nimonic 75 should be chromium content 20.0 % and nickel content 80.0 %.

Metal Transfer in Sigma Welding

Metal transfer in the arc is studied by ultraslow motion photography and the effect of different welding conditions, current, gas mixtures and rod material are noted

by R. T. Breymeier

INTRODUCTION

THIS paper deals with the results obtained when applying the sigma (shielded-inert-gas-metal-arc) welding process under a variety of specific conditions of current, shielding gas, and rod material, and how some of these results are dependent on the metal transfer in the arc. Under most conditions, the mechanism of metal transfer can be studied best by ultraslow motion photography. Here, some of these observations will be described, and illustrations are given of how this metal transfer affects actual weld beads.

To be of practical value, any particular set of welding conditions must lead to a useful result. When sigma welding was first introduced, such useful results were most readily achieved by employing direct current of reverse polarity. With this current direction the metal transfer was more regular and steady under a wide variety of conditions, such as varying current magnitude and rod diameter. However, since that time, further investigation has shown that the use of straight polarity is not only feasible under certain conditions, but, for some applications, has inherent advantages.

Additions of oxygen to argon have been found to have a pronounced effect on the metal transfer of some materials. This has led to the introduction of Linde's sigma grade argon (a mixture of high-purity oxygen and argon), which has widened the range of applications of direct current-straight polarity considerably beyond those possible with either pure argon or helium.

The effects of changes in the gas composition as well as of the current direction also vary with different materials. Each of the three metals considered in this paper (steel, stainless steel and aluminum) will, therefore, be treated separately. It should be emphasized that any of the conclusions drawn for one of these metals does not necessarily apply to the others.

For convenience, all the comparative data presented here were obtained from beads made on flat plates using $^1/_{16}$-in. diameter welding wire and one welding speed. For each case currents ranged from about 100 to 500 amp. and were supplied by a conventional motor-generator machine. The arc lengths were held at what is generally considered best practice by means of a manual and, in some cases, by an automatic rod speed control.

In interpreting the beads pictured, care should be taken to realize that when actual welds are made, variations in travel speed and the use of various edge preparations will frequently change bead contours and penetration characteristics considerably. To aid in explaining such changes, a cross section of an actual butt weld is also shown.

STEEL

The welding of steel by the sigma process is not as yet too well established commercially. The best methods and limits of application are still to be determined in many cases. However, the results of the series of weld beads presented here should be of value in forming an opinion as to which particular set of conditions might be most useful for a particular job. Figures 1 and 2 show the top surfaces and the cross sections of beads made on $^3/_8$-in. thick steel, using a $^1/_{16}$-in. diameter filler wire at a welding speed of 30 in. per minute. The variations of bead shapes which are produced at any given current with the two polarities and two gases are most significant and show that some flexibility is present by choosing the proper combination.

Until recently, sigma welding was generally carried out in atmospheres of either argon or helium, the only gases of the inert gas group economically feasible for shielding. Of these two, argon was generally found more practical for sigma welding of steel due to the lower amount of spatter produced. With either gas there is a limiting minimum current which can be used, for any given rod diameter. Below this current, at which the metal transfer becomes unsatisfactory for producing a continuous and even weld bead, the wire melts off in the form of large globules severed from the rod end primarily by the force of gravity in a rather irregular manner. This results in separate drops lying on the base metal with little penetration. Above this minimum current, small particles are ejected in an orderly fashion at high velocity from the lower end of the filler wire, producing a smooth, even bead. With straight polarity and argon protection this minimum current is rather high as can be seen in Fig. 1.

To offset this undesirable condition, Linde's sigma grade argon has been introduced. When using this gas, the metal transfer of steel is changed considerably, particularly at the lower currents. The effects on the beads made with straight polarity are very noticeable in Fig. 1, but other effects, such as a reduced tendency toward undercutting and a better weld contour are also produced when using this gas mixture with reverse polarity current. It has been found that additions of oxygen to helium produce just the opposite effect, in that they raise the minimum current at which acceptable metal transfer takes place.

While Fig. 2 shows the variation in penetration and bead contour which is available by using the different conditions discussed, it does not show the effect of varying the arc length. Longer arcs generally tend to produce flatter, wider beads with less penetration, and shorter arcs, narrower beads with greater penetration. Weld nuggets made by the sigma process at the higher currents produce a characteristically deep penetration at the center line. This tip is clearly visible in the cross sections of Fig. 2. It originates because of the high velocity and force which the liquid particles achieve while traveling across the welding arc. Such a weld nugget contour can be employed to advantage in many cases as it makes deep penetration possible where it is necessary, without causing undue dilution. Figure 3 gives an example where the tip produced the neces-

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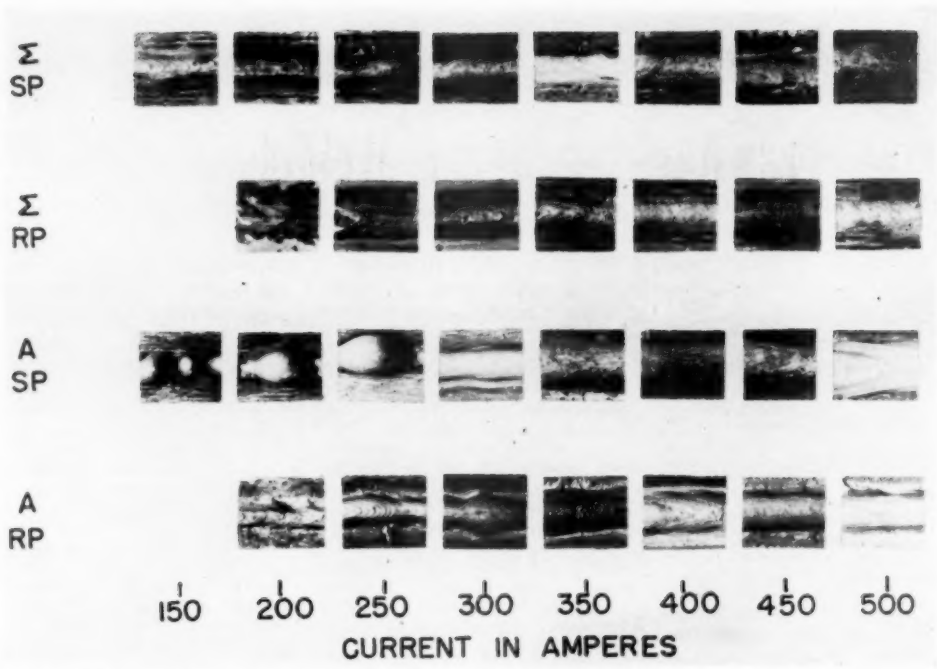


Fig. 1 Effect of current direction, amperage, and gas on surface appearance of beads made with 1/16-in. diam. steel wire

NOTE—In all figures the following abbreviations have been used: RP = direct current reverse polarity, SP = direct current straight polarity, A = argon, Σ = sigma grade argon. The currents used for the beads shown in the photographs correspond only approximately to those indicated.

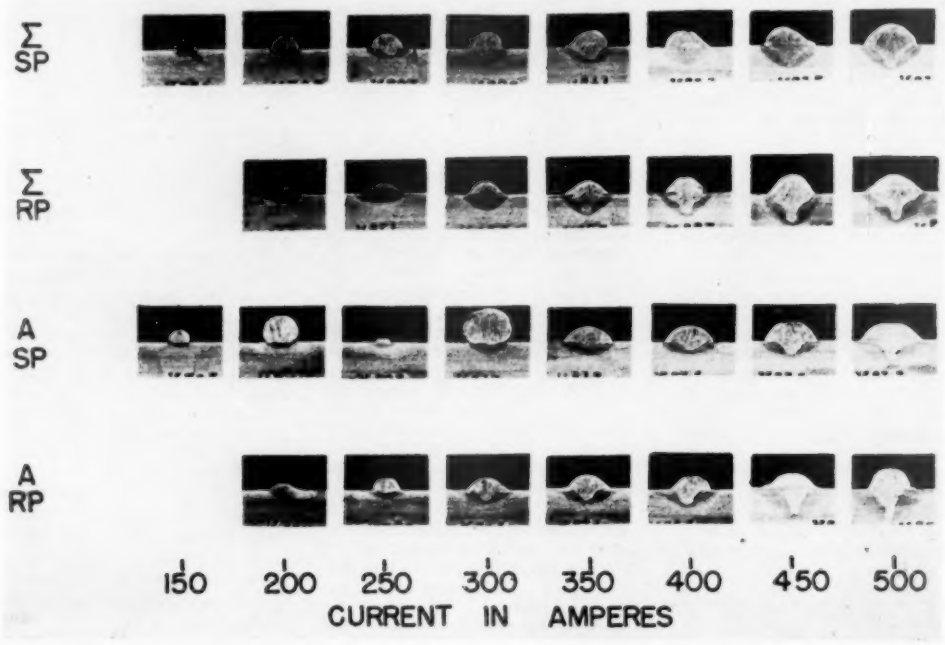


Fig. 2 Effect of current direction, amperage, and gas shield on cross sections of beads made with 1/16-in. diam. steel wire

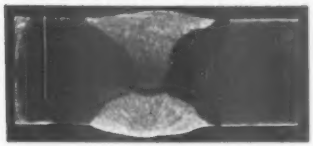


Fig. 3 Cross section of two-pass butt weld in 1-in. thick low-alloy steel using 630 amperes direct current straight polarity, sigma grade argon and 1/8-in. diam. wire. The plate was prepared with a sharp nose, double bevel of 70-degree included angle

sary overlapping between the beads deposited from opposite sides in 70-degree vee grooves. This cross section also illustrates that smooth surface contours can readily be achieved in welds despite the fact that the beads shown in Fig. 2 have rather steep sides.

The sigma welding process is generally considered to have rather high metal deposition rates, but, for a given current, this rate varies with the type of current and gas protection used. Figure 4 shows the rod speeds recorded in producing the beads shown in Figs. 1 and 2. It is interesting to note that although the addition of oxygen to argon has a pronounced effect on the mechanism of metal transfer, the rate of rod consumption is not greatly affected.

The dotted section of the curve representing the rod speed with straight polarity under argon in Fig. 4 indicates that in this range of current the transfer rate of drops from the wire was so low that a completely unusable bead was produced. This is apparent by inspection of Fig. 1. With sigma grade argon, the drop transfer rate was sufficiently increased so that continuous smooth beads were produced at currents down to about 130 amp. In all the graphs, dotted lines represent conditions leading to poor beads.

The arc voltages normally encountered with sigma welding are somewhat different with the different welding conditions. Figure 5 shows voltages measured while producing the beads in steel. These measurements include not only the voltage across the arc but also certain resistance drops. One of these is the contact resistance drop between the rod guide tube and the rod. These resistance drops are probably primarily responsible for the general rise in voltage with increasing current. Under helium, the arc voltage is higher than for argon, and with all gases it varies with the arc length.

The following are a number of general conclusions which can be drawn from the data obtained from the weld beads made on steel:

1. For a given current, argon with reverse polarity produces the deepest and narrowest penetration.

2. With reverse polarity, sigma grade argon produces a more desirable bead contour than does argon.

3. When using straight polarity, sigma grade argon makes it possible to produce acceptable beads at much lower currents than is possible with regular argon.

4. The penetration obtained with straight polarity is generally less than with reverse polarity.

5. The metal deposition rate with straight polarity is from 25 to 50% greater than with reverse polarity.

STAINLESS STEEL

The sigma welding process has been used much more extensively on stainless steel than it has on carbon steel, and with the recent introduction of sigma grade argon, it is expected to find even more favor since this gas makes it possible to weld at higher speeds and with lower currents. This extends the range of the process to considerably lighter gage material than was previously considered practical. Sigma grade argon lowers the minimum feasible current to quite an extent when using either direct current-reverse or -straight polarity. The type of beads and penetration produced with the two polarities and two gases can be seen in Figs. 6 and 7. All the beads shown here were made at 30 in. per minute travel speed, with 1/16-in. diameter wire on 3/8- and 3/16-in. plate. Again, as with carbon steel, the different conditions covered show that some variation in bead contour and shape can be achieved.

From ultraslow motion pictures it has been learned that the metal transfer mechanism with straight and reverse polarities is radically different, and that oxygen additions to argon have a profound effect on this metal transfer.

Rod consumption with both gases is from 50 to 75% higher using straight polar-

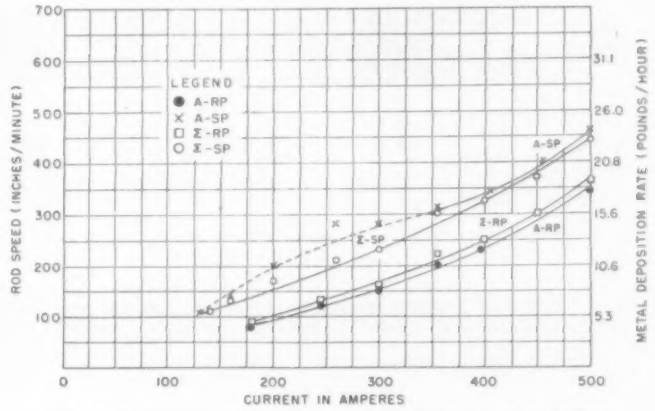


Fig. 4 Effect of current on the rate of consuming 1/16-in. steel wire

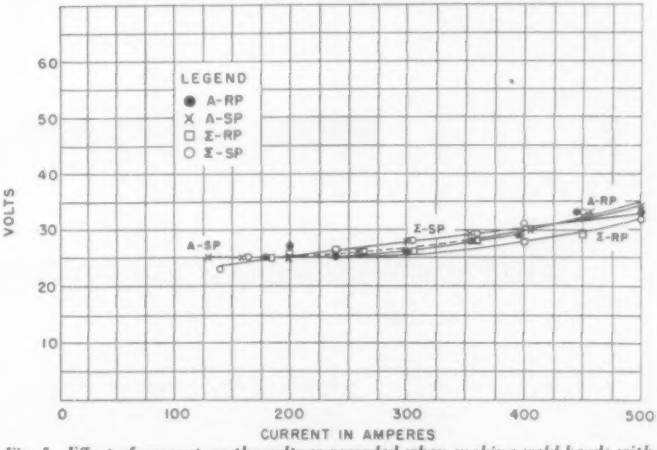


Fig. 5 Effect of current on the voltage recorded when making weld beads with 1/16-in. steel wire

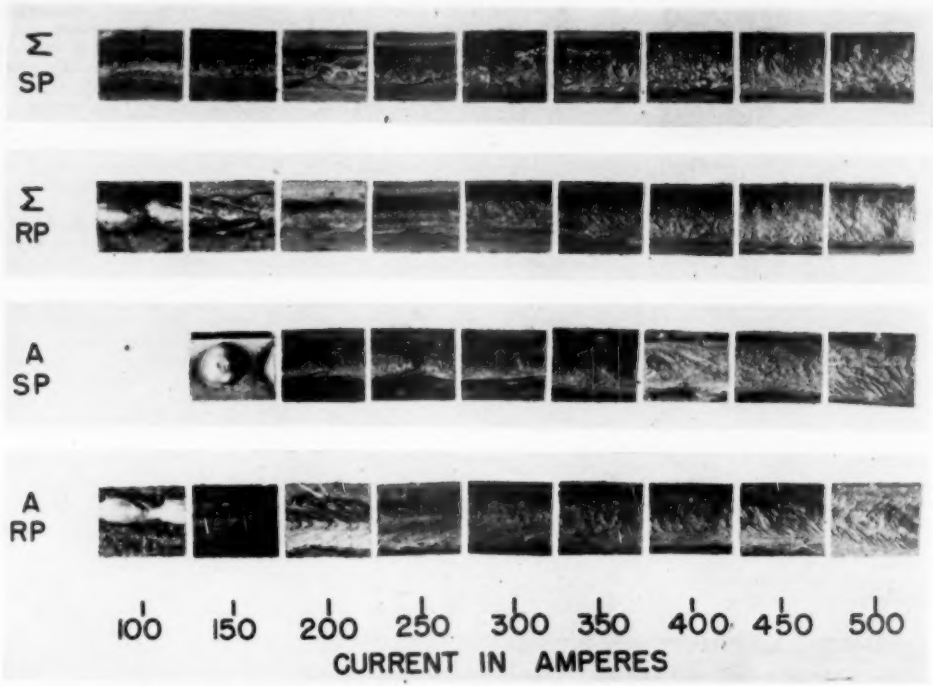


Fig. 6 Effect of current direction, amperage, and gas on surface appearance of beads made with $^{1}/_{16}$-in. diam. stainless steel wire

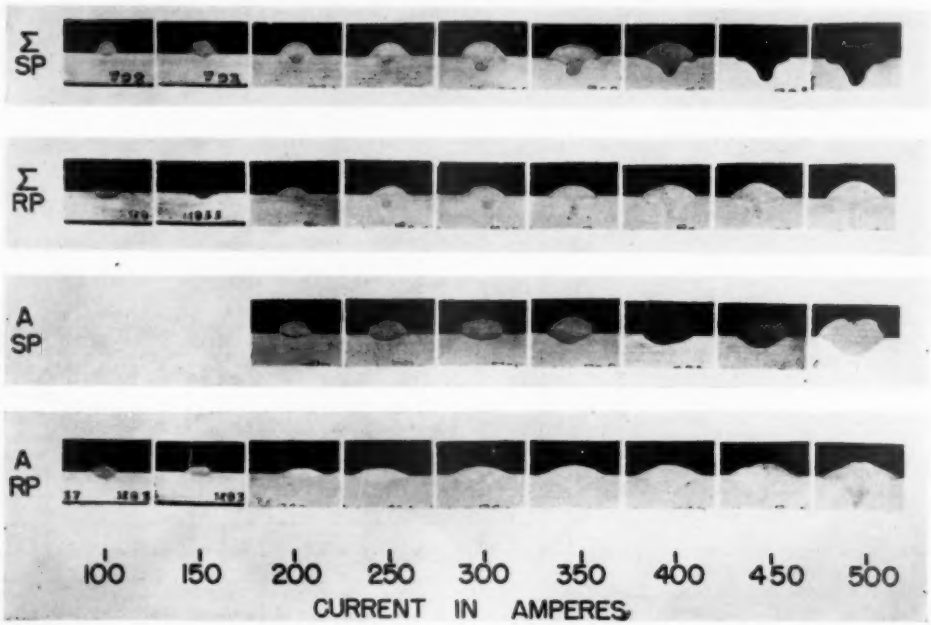


Fig. 7 Effect of current direction, amperage, and gas on the cross sections of beads made with $^{1}/_{16}$-in. stainless steel wire

Fig. 8 Weld beads made with $^1/_{16}$-in. stainless steel wire using 280 amperes direct current reverse polarity and argon at a travel speed of 300 in. per minute

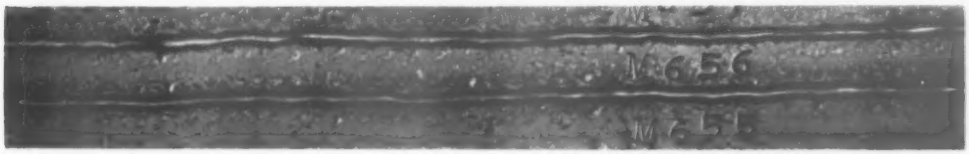


Fig. 9 Weld beads made with $^1/_{16}$-in. stainless steel wire using 280 amperes direct current reverse polarity and sigma grade argon at a travel speed of 300 in. per minute

ity rather than reverse polarity. This fact can be of considerable benefit on many applications. The presence of oxygen in argon does not affect the rod melt-off rate of stainless steel to any great extent when using reverse polarity (Fig. 10).

Figures 8 and 9 illustrate the effect of oxygen additions to argon in increasing the drop rate when using reverse polarity. The beads shown in both these figures were produced with a current of 280 amp. at 300 in. per minute travel speed. Pure argon was used as the shielding gas for the beads in Fig. 8, and sigma grade argon for those in Fig. 9. This illustration is given to show how important an increase in drop rate can be when welds are to be made at high speed.

Figure 11 gives the voltages recorded while making the beads shown in Figs. 6 and 7. Here again the general rise in voltage with current is probably mainly due to wire resistance and contact resistance between guide tube and wire, rather than due to an increase in the arc voltage itself.

The following are a few general conclusions which apply to sigma welding of stainless steel:

1. A variation of bead width, penetration and metal deposition rates can be obtained by varying the current direction and gas used as the shielding medium.

2. Straight polarity produces higher metal deposition rates for the same amperage.

3. Sigma grade argon makes the use of low currents feasible, particularly in conjunction with straight polarity.

ALUMINUM

This material was the first to be successfully handled by sigma welding and still

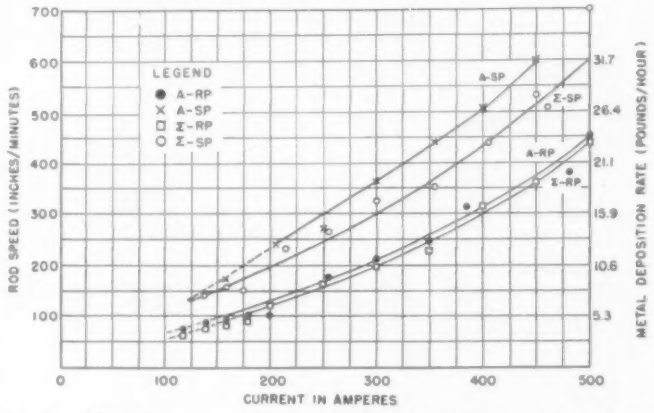


Fig. 10 Effect of current on the rate of consuming $^1/_{16}$-in. stainless steel wire

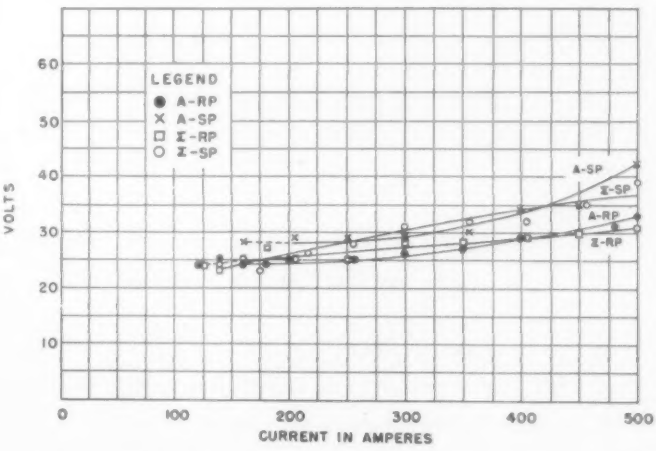


Fig. 11 Effect of current on the voltage recorded when making weld beads with $^1/_{16}$-in. steel wire

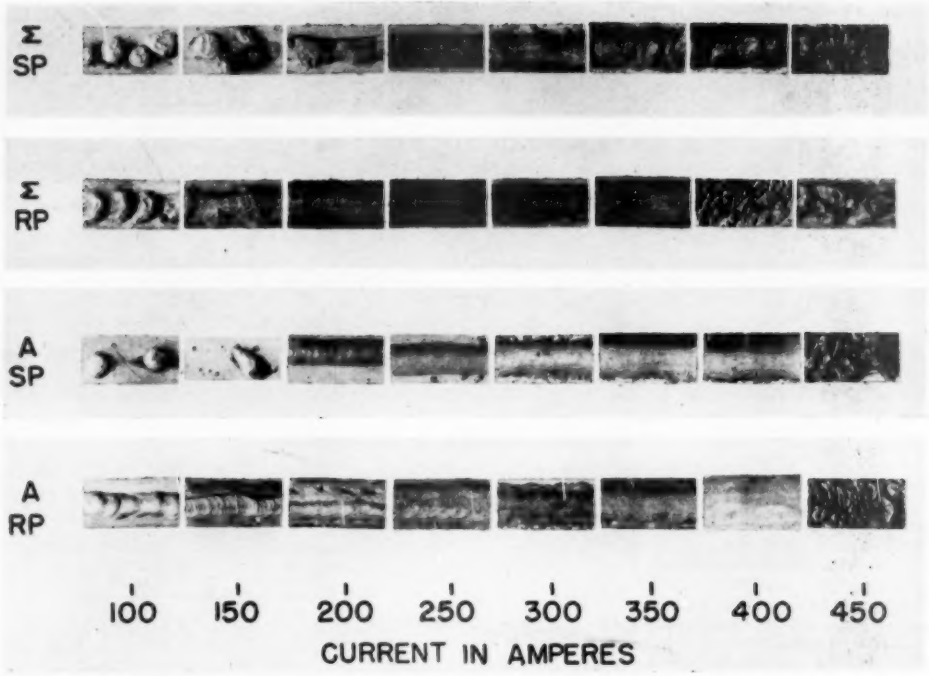


Fig. 12 Effect of current direction, amperage, and gas on the surface appearance of beads made with $^1/_{16}$-in. diam. aluminum wire

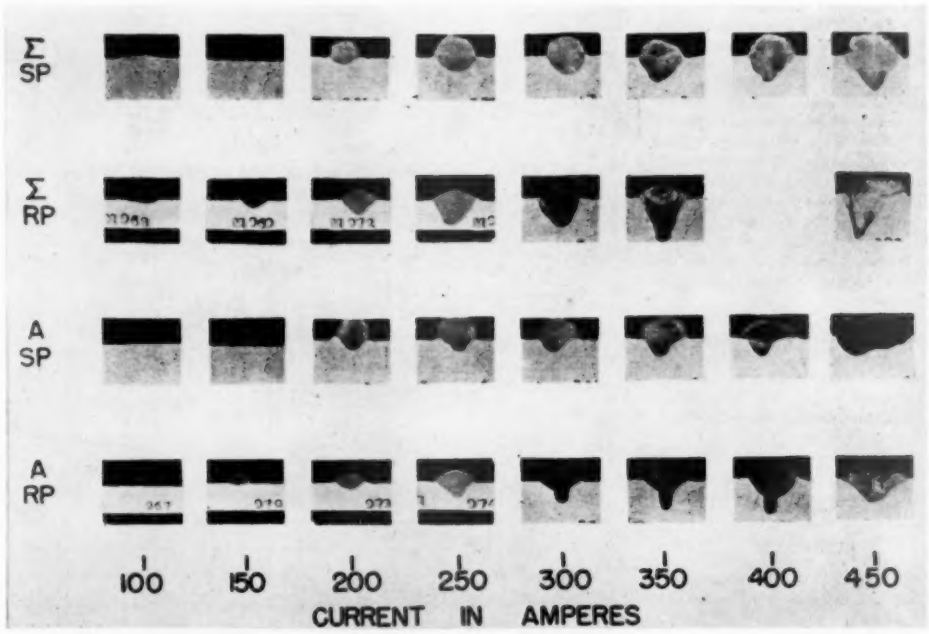


Fig. 13 Effect of current direction, amperage, and gas on the cross sections of beads made with $^1/_{16}$-in. diam. aluminum wire

represents its greatest field of application. As with gas-shielded-tungsten arc welding, no flux is required with this process. Because of the high metal deposition rates possible with sigma welding it has displaced the tungsten arc process in many applications. These high deposition rates make it extremely useful in joining heavy plates for such applications as tank cars. However, it has also been applied very successfully to lighter material where high welding speeds with the addition of filler metal are essential. To date, it has generally been operated with direct current-reverse polarity and argon protection, but it is also possible, under certain limited conditions, to produce beads and welds with straight polarity using helium or sigma grade argon.

Each current and gas combination used with aluminum and aluminum alloy rods has an upper as well as lower current limit which will produce smooth, continuous beads. The lower limit is imposed on the process by the drop transfer rate, which becomes very slow and erratic at low currents. Also, with straight polarity the penetration becomes very light at low currents so that the large metal drops hardly adhere to the base plate.

Figures 12 and 13 show beads produced on $^1/_2$- and $^1/_4$-in. aluminum plate with $^1/_{16}$-in. diameter rod under argon and sigma grade argon and the two polarities. These beads made at 30 in. per minute distinctly show the effect of too low a current for each of the different conditions.

If the current is sufficiently high to produce a steady metal transfer drop rate and the drop velocity is adequate to produce some penetration, reasonably acceptable beads can be produced with each gas and current combination up to a maximum current where the beads or welds will exhibit deep oxide folds. This maximum current varies to some extent with the conditions involved and also with the rod diameter used, but with aluminum and aluminum alloys it will generally be between 300 and 450 amp. for the two gases shown as well as for helium. So far, no practical method has been found of extending this maximum current much beyond these limits. Figure 13, picturing the cross sections of the beads, serves as a means of comparing the penetration obtained under the various conditions.

When using reverse polarity, the addition of oxygen to argon has little effect on the rate of metal transfer. This is clearly shown in Fig. 14 where the two curves nearly overlap. However, by changing to straight polarity, this metal deposition rate can be increased some 50 to 100%, depending on the magnitude of the current and the gas. This is, of course, of considerable value where buildup is of primary concern.

Figure 15 shows the voltages used to produce the beads discussed here. The reason that these curves are much flatter than the equivalent ones for steel and stainless steel probably lies in the lower

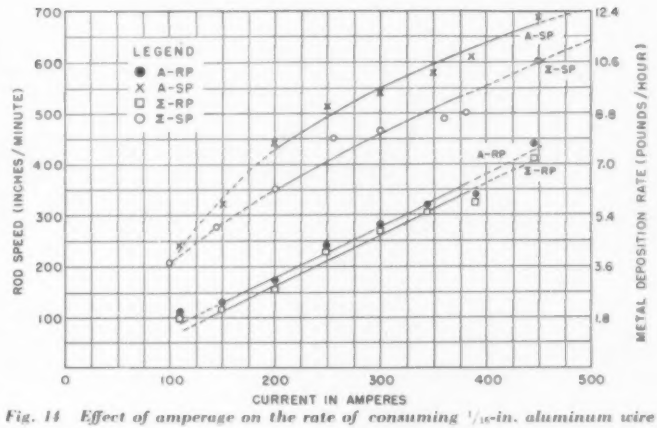


Fig. 14 Effect of amperage on the rate of consuming $^1/_{16}$-in. aluminum wire

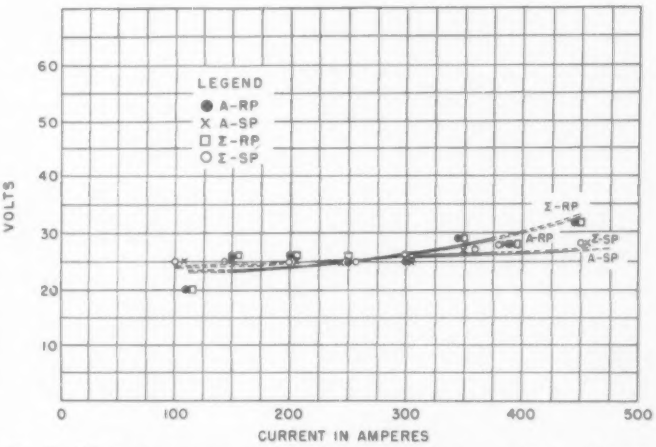


Fig. 15 Effect of amperage on the voltage recorded when making weld beads with $^1/_{16}$-in. aluminum wire

electrical resistance of the aluminum wire as compared to that of the ferrous metals. The smaller variation of voltage with the different gases is also of interest.

The following are a few generalizations which can be made about these conditions for sigma welding aluminum:

1. The addition of oxygen to argon does not have much affect on the metal deposition rate with direct current-reverse polarity.
2. The addition of oxygen to argon does not materially change the drop rate.
3. Under certain conditions, usable bead forms can be produced with direct current-straight polarity.
4. Metal deposition rates with direct current-straight polarity are considerably higher than with direct current-reverse polarity.
5. The occurrence of oxide folds sets an upper limit of about 300 to 450 amp. on sigma welding of aluminum.

GENERAL CONCLUSIONS

The data presented here should be of value in comparing results to be expected from the use of direct current-reverse polarity and direct current-straight polarity with argon and sigma grade argon. It is apparent that a wider range of results can be obtained than has generally been assumed, and with future developments, the process should become adaptable to many more applications. However, for its success it is necessary for those applying it to understand its potentialities and characteristics of operation, and it is the intention of this paper to help spread this information.

Effects of Nose Design on Spot Welding Electrodes

Examination of the performance of various standard designs of spot welding electrodes under electrical welding operations in terms of weld quality and electrode life

by E. F. Holt and L. W. Sink

INTRODUCTION

IN THE spot welding of metals, the question of the most desirable electrode shape is a common one. Nearly every shop—even each machine operator—has a favorite electrode size and shape, often without regard to such salient considerations as weld consistency and appearance, electrode life and loss of production through downtime caused by frequent electrode dressing or replacement. It is a matter of concern and economic loss when production plants do not assure themselves that the best available electrode designs are being used in their operations.

Much engineering thought and experience has gone into the design of spot welding electrodes. The purpose of the investigation reported in this paper is to examine various standard designs under actual welding operations and to evaluate their relative performances in terms of weld quality and consistency and electrode life. In long-run welding operations, the use of an electrode design which provides minimum electrode deterioration assures the maximum return for machine and operator time and consequently greater economy of production.

It is a regrettable fact, however, that many an operator can and does destroy the value of a well-engineered electrode design by a savage attack with a coarse file. This condition can be corrected only by better operator training and by supplying the proper tools for maintaining the initial electrode nose contour.

ELECTRODE DESIGN

Nine representative common electrode nose contours were selected for testing. Details of these designs are shown in Fig. 1. All electrodes were made of Mallory 3 metal, an R.W.M.A. Class 2 alloy. Eight of the electrode styles were made with

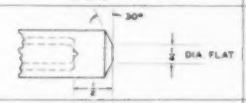
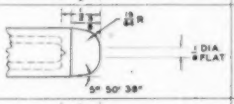
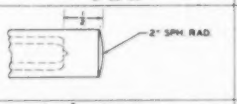
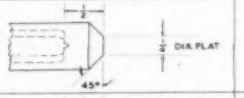
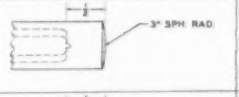
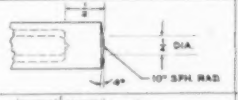
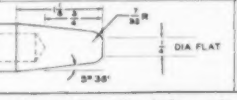
ELECTRODE DESIGN NO.	DESIGN	DESCRIPTION
AW-1872		POINTED NOSE - FLUTED WATER HOLE - 1/2" NOSE LENGTH
AW-1873		TRUNCATED CONE - FLUTED WATER HOLE - 1/2" NOSE LENGTH
AW-1874		DOME NOSE - FLUTED WATER HOLE - 1/2" NOSE LENGTH
AW-1875		2" RADIUS FACE - FLUTED WATER HOLE - 1/2" NOSE LENGTH
AW-1876		MODIFIED POINTED M-11 NOSE FLUTED HOLE - 1/2" NOSE LENGTH
AW-1877		45° TRUNCATED CONE - FLUTED WATER HOLE - 1/2" NOSE LENGTH
AW-1878		3" RADIUS FACE - FLUTED WATER HOLE - 1/2" NOSE LENGTH
AW-1879		10" RADIUS WITH 4° APPROACH ANGLE FLUTED HOLE - 1/2" NOSE LENGTH
AW-1885		ST'D RWMA-A2210 POINTED NOSE ROUND HOLE - 3/4" NOSE LENGTH

Fig. 1 Details of electrode nose design

E. F. Holt is Chief Engineer and **L. W. Sink** is Research Engineer with P. R. Mallory & Co., Inc., Welding Division, Indianapolis, Ind.

fluted water holes and a $^1/_8$-in. nose length; while the other, AW-1885, had a $^3/_8$-in. diameter round water hole and a $^3/_8$-in. nose length. In this paper, the term "nose length" is defined as the distance between the bottom of the water hole and the welding face. All electrodes had a $^1/_8$-in. major diameter, No. 2 Morse Taper, and an over-all length of $2^1/_2$ in.

The fluted water hole developed by P. R. Mallory & Co., Inc., provides a cooling area 70% greater than the round water hole. The $^1/_8$-in. nose length has been standardized for all fluted electrodes except the radius faced electrodes.

The AW-1885 design is the standard R.W.M.A. A-2210 pointed nose electrode. This electrode style has been widely

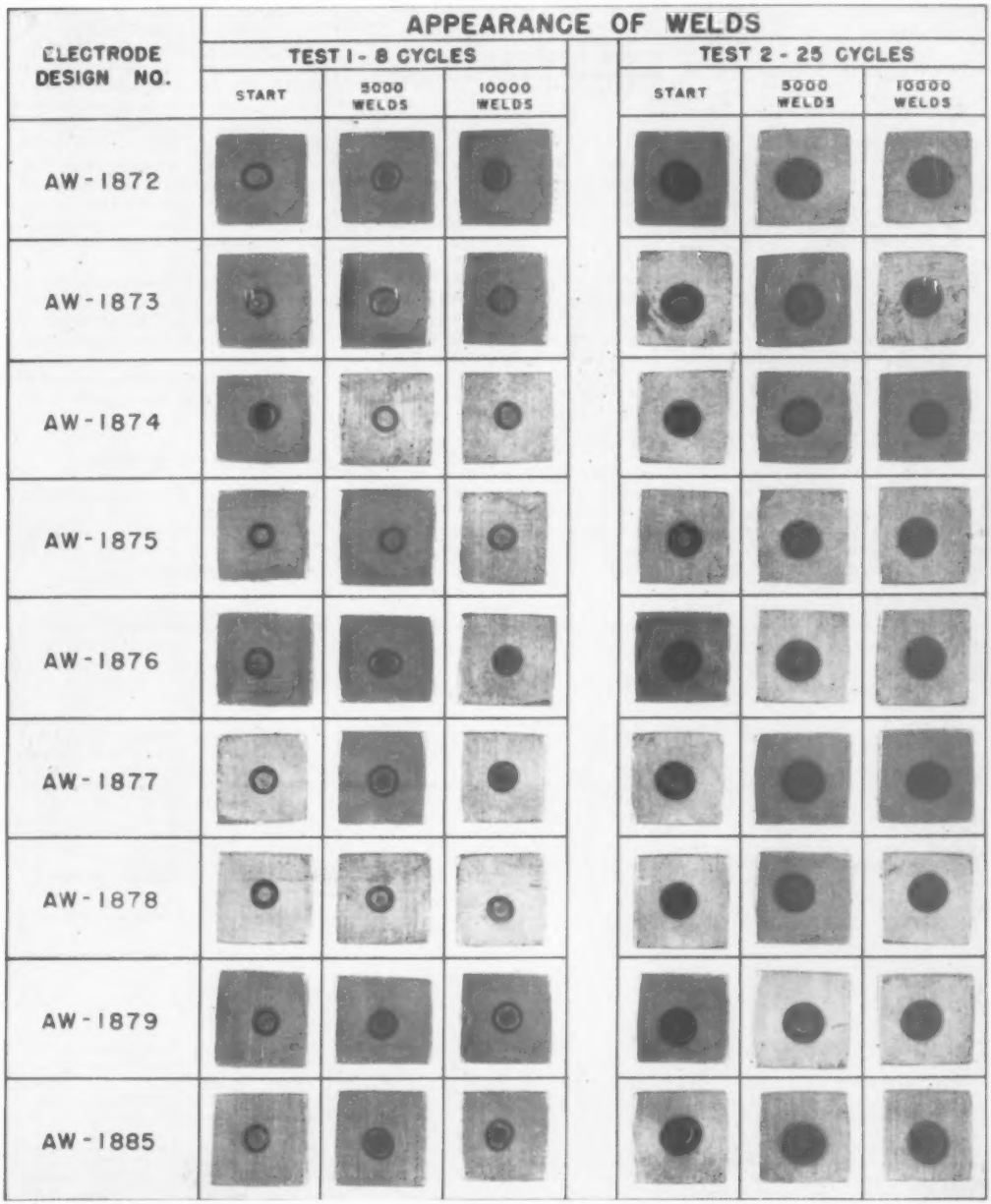


Fig. 2 Weld appearance and symmetry

accepted and used in the resistance welding trade and was therefore selected as a control and a basis for comparison for the other test electrodes.

TEST PROCEDURE

Each electrode design was subjected to two distinct welding tests under the following conditions:

		Test 1	*Test 2*
1.	Electrode force, lb.	750	600
2.	Squeeze time, cycles	11	12
3.	Weld time, cycles	8	25
4.	Hold time, cycles	19	16
5.	Welder speed, strokes/min.	50	50
6.	Water flow rate, gal./electrode/min.	1.0	1.0
7.	Welder head push-up, in.	1/4	1/4
8.	Welding current, amp.		
	AW-1872	11,466	10,600
	AW-1873	11,466	9,275
	AW-1874	10,062	8,480
	AW-1875	10,062	9,275
	AW-1876	11,466	9,010
	AW-1877	11,466	9,275
	AW-1878	10,062	9,275
	AW-1879	11,466	9,275
	AW-1885	11,466	9,275

The welding current was set initially for each electrode design to yield welds of approximately equal shear strength and was maintained at the predetermined value throughout each test run.

Each test consisted of making 10,000 spot welds on two thicknesses of 0.050-in. half-hard, cold-rolled, mild steel with the properties shown in Table 1.

Table 1—Composition and Properties of Work Material

Composition:	
Carbon, %	0.06
Manganese, %	0.30
Ultimate Tensile Strength, psi.	68,220
Elongation in 2 in., %	12.5
Hardness, Rockwell "B"	81

The steel was clean and was prepared for welding by degreasing in carbon tetrachloride and wiping with clean cloths.

A 100-kva. motor-driven, press-type, air-cushioned welder with a synchronous ignitron controller was used. Welding currents were constantly checked by means of a pointer-stop ammeter connected with a clamp-type current transformer placed around the lead to the transformer primary. The water flow rate to each electrode was indicated continuously by a Rotameter.

The details of the test procedure were, as follows:

1. At the start and at each 250-weld interval, three tension-shear specimens (A.W.S. standard 1- x 4-in. lap) were welded in a fixture to assure correct alignment and overlap. The shear strength of each specimen was determined on a tensile testing machine.

2. At the start and at each 500-weld interval: (*a*) Three appearance welds were made on a running log sheet consisting of two thicknesses of 0.050-in. steel, 6 x 12 in. (*b*) The test electrodes were reversed in the upper and lower holders and were rotated 90 degrees in opposite directions to avoid localized deformation of the welding face.

3. At the start and at the completion of 10,000 spot welds: (*a*) Hardness measurements were made on the electrode face. (*b*) The diameter of the welding face and the nose contour were measured on a projection comparator providing a magnification of 10 ×. (*c*) The over-all length of the electrode was measured. (*d*) Three sample welds were sectioned, polished and etched. The diameter of the weld nugget, the weld penetration and the soundness of the weld were determined under a microscope.

4. At the completion of tests 1 and 2, photographs were taken of the test electrodes to provide a visual comparison of the effects of the welding operation on the various designs.

5. The running log sheets were x-rayed to determine the quality of the welds.

DISCUSSION OF RESULTS

Characteristics of the Welds

The data pertinent to the weld characteristics are shown in Tables 2 and 3 for tests 1 and 2, respectively.

Table 2—Weld Characteristics from Test 1

Electrode design no.	*Description of electrode*	*Welding current, amp.*	*Weld shear strength, lb.*			*Deviation from average shear strength, %*		*Weld diameter, in.*			*Weld penetration, %*		
			High	*Av.*	*Low*	*High*	*Low*	*Initial*	*Final*	*Change*	*Initial*	*Final*	*Change*
AW-1872	Pointed	11,466	2299	2221	2152	3.5	3.1	0.228	0.197	−0.031	67.9	77.5	+9.6
AW-1873	30-degree truncated cone	11,466	2278	2194	2114	3.8	3.6	0.192	0.196	+0.004	73.1	75.7	+2.6
AW-1874	Dome	10,062	2159	2096	2025	3.0	3.5	0.161	0.196	+0.035	80.2	75.7	−4.5
AW-1875	2 in. radius	10,062	2178	2097	2036	3.9	2.9	0.218	0.218	0	73.9	74.2	+0.3
AW-1876	Modified pointed	11,466	2303	2206	2118	4.4	4.0	0.203	0.187	−0.016	86.0	70.0	−16.0
AW-1877	45-degree truncated cone	11,466	2293	2199	2094	4.3	4.8	0.218	0.250	+0.032	71.5	77.0	+5.5
AW-1878	3 in. radius	10,062	2195	2124	2052	3.3	3.4	0.203	0.198	−0.005	82.5	75.5	−7.0
AW-1879	10 in. radius, 4-degree angle	11,466	2284	2220	2160	2.9	2.7	0.200	0.196	−0.004	72.6	75.2	+2.6
AW-1885	Standard pointed	11,466	2329	2223	2115	4.7	4.9	0.219	0.221	+0.002	77.0	77.0	0

Table 3—Weld Characteristics from Test 2

Electrode design no.	*Description of electrode*	*Welding current, amp.*	*Weld shear strength, lb.*			*Deviation from average shear strength, %*		*Weld diameter, in.*			*Weld penetration, %*		
			High	*Av.*	*Low*	*High*	*Low*	*Initial*	*Final*	*Change*	*Initial*	*Final*	*Change*
AW-1872	Pointed	10,600	2583	2483	2375	4.0	4.3	0.271	0.268	−0.003	83.2	79.4	−3.8
AW-1873	30-degree truncated cone	9,275	2539	2409	2244	5.4	6.8	0.269	0.266	−0.003	84.0	85.0	+1.0
AW-1874	Dome	8,480	2388	2319	2212	3.0	4.6	0.250	0.207	−0.043	76.5	74.5	−2.0
AW-1875	2 in. radius	9,275	2510	2417	2340	3.9	3.2	0.239	0.204	−0.035	76.2	69.8	−6.4
AW-1876	Modified pointed	9,010	2485	2358	2220	5.4	5.8	0.237	0.232	−0.005	63.5	71.3	+7.8
AW-1877	45-degree truncated cone	9,275	2459	2384	2262	3.1	5.1	0.233	0.232	−0.001	79.4	75.0	−4.4
AW-1878	3 in. radius	9,275	2521	2438	2351	3.4	3.6	0.233	0.243	+0.010	71.5	76.7	+5.2
AW-1879	10 in. radius, 4-degree angle	9,275	2520	2426	2307	3.9	4.9	0.231	0.243	+0.012	75.4	74.6	−0.8
AW-1885	Standard pointed	9,275	2553	2425	2253	5.3	7.1	0.261	0.262	+0.001	69.7	77.0	+7.3

Within the scope of the 10,000-weld runs, weld strength and consistency were not adversely affected by electrode deterioration. If the tests had been continued over a greater number of welds, perhaps 50,000 spots, more definite effects on weld quality, sticking between electrodes and work and metal expulsion could be expected.

The results, however, indicate that more consistent welds are obtained with electrode welding faces having a true spherical radius or approaching a spherical radius, as is the case with AW-1875 (2 in. radius), AW-1878 (3 in. radius), AW-1879 (10 in. radius, 4-degree angle, 1/8-in. diameter face) and AW-1874 (dome). Closely following this group in weld consistency are the AW-1872 electrodes, the blunt pointed nose design.

A comparison of the weld appearance and symmetry afforded by the various electrodes is shown in Fig. 2, a photograph of coupons cut from the weld log sheets. Again it is apparent that the radius-faced and allied electrodes provide better weld

Table 4—Electrode Performance in Test 1

Electrode design no.	*Description of electrodes*	*Hardness of welding face —Rockwell "B"—*			*Diameter of welding face —in.—*		*Area of welding face, sq. in.*		*Increase in area, %*	*—Electrode length, in.—*			*Extent of oxidation from welding face, in.*
		Initial	*Final*	*Loss*	*Initial*	*Final*	*Initial*	*Final*		*Initial*	*Final*	*Loss*	
AW-1872	Pointed-blunt	87.5	54.0	33.5	0.250	0.325	0.0491	0.083	69.4	2.510	2.507	0.003	1/4
AW-1873	30-degree truncated cone	81.0	55.0	26.0	0.250	0.377	0.0491	0.112	128.6	2.500	2.491	0.009	1/16
AW-1874	Dome	85.0	63.0	22.0	0.150	0.320	0.018	0.080	344.0	2.495	2.490	0.005	1/8
AW-1875	2 in. radius	84.0	71.0	13.0	.....	.....	.....	.....	.....	2.506	2.504	0.002	*
AW-1876	Modified pointed	87.0	51.0	36.0	0.265	0.407	0.055	0.130	136.4	2.512	2.505	0.007	9/32
AW-1877	45-degree truncated cone	83.0	51.0	32.0	0.240	0.375	0.045	0.116	144.6	2.505	2.491	0.014	3/32
AW-1878	3 in. radius	84.0	65.0	19.0	.....	.....	.....	.....	.....	2.505	2.502	0.003	*
AW-1879	10 in. radius, 4-degree angle	82.0	51.0	31.0	.....	.....	.....	.....	.....	2.504	2.502	0.002	*
AW-1885	Standard pointed	81.0	45.0	36.0	0.220	0.440	0.038	0.152	300.0	2.495	2.470	0.025	1/2

* Confined to welding face.

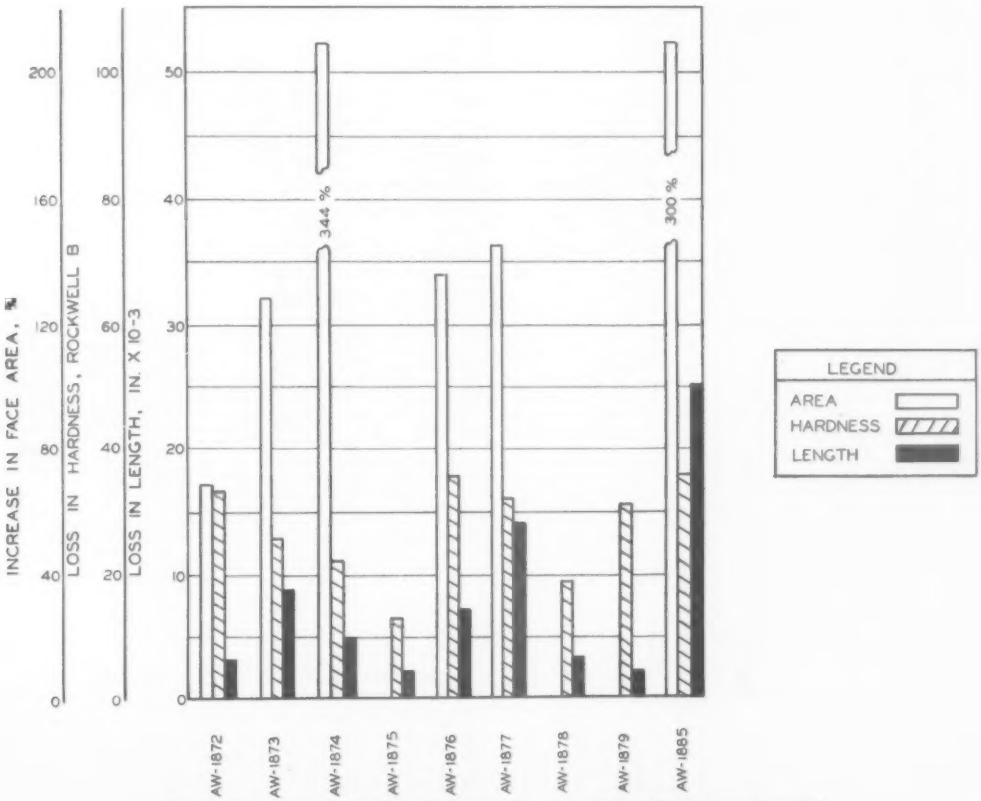


Fig. 3 Chart from electrode performance data from Test 1 (Weld time—8 cycles)

appearance and greater symmetry over the entire test run.

The radiographs of the weld log sheets showed that all welds were dense and sound, with no indications of cracks or porosity. The soundness of the welds was further verified by the metallographic study of the weld cross sections.

Performance Characteristics of Electrodes

Although the characteristics of the spot welds fail to show any clear-cut advantage of one design over another within the limits of the tests, the effects of the welding operations on the electrodes themselves show a definite superiority for the radius-faced electrodes and others of comparatively blunt nose design.

The loss in hardness and electrode length and the increase in welding face area (mushrooming) are shown in Tables 4 and 5 and graphically in Figs. 3 and 4. These are data particularly pertinent to the life of any spot-welding electrode and to the

Table 5—Electrode Performance in Test 2

Electrode design No.	*Description of electrodes*	*Hardness of welding face —Rockwell "B"—*			*Diameter of welding face —in.—*		*Area of welding face, sq. in.*		*Increase in area, %*	*—Electrode length, in.—*			*Extent of oxidation from welding face, in.*
		Initial	*Final*	*Loss*	*Initial*	*Final*	*Initial*	*Final*		*Initial*	*Final*	*Loss*	
AW-1872	Pointed-blunt	88.0	38.0	50.0	0.250	0.350	0.049	0.096	96.0	2.510	2.505	0.005	7/16
AW-1873	30-degree truncated cone	82.0	34.0	48.0	0.250	0.360	0.049	0.102	107.2	2.500	2.489	0.011	9/32
AW-1874	Dome	84.0	44.0	40.0	0.150	0.328	0.018	0.084	366.0	2.495	2.487	0.008	5/16
AW-1875	2 in. radius	80.0	47.0	33.0	.....	.....	.....	.....	.....	2.506	2.502	0.004	11/32
AW-1876	Modified pointed	86.0	32.0	54.0	0.260	0.410	0.053	0.132	149.0	2.512	2.497	0.015	7/16
AW-1877	45-degree truncated cone	85.0	42.0	43.0	0.240	0.410	0.045	0.132	215.5	2.505	2.485	0.020	3/4
AW-1878	3 in. radius	82.0	44.0	38.0	.....	.....	.....	.....	.....	2.505	2.501	0.004	5/16
AW-1879	10 in. radius 4-degree angle	86.0	46.0	40.0	.....	.....	.....	.....	.....	2.504	2.500	0.004	5/16
AW-1885	Standard pointed	82.0	25.0	57.0	0.240	0.467	0.045	0.171	280.0	2.495	2.460	0.035	9/16

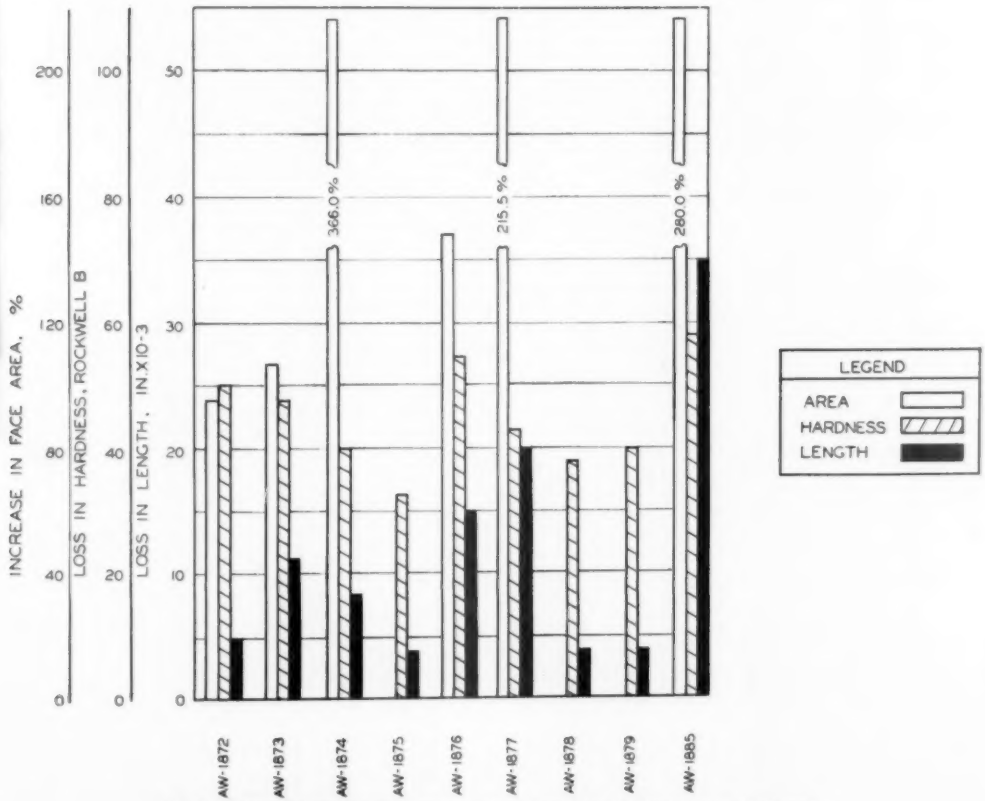


Fig. 4 Chart of electrode performance data from Test 2 (Weld Time—25 Cycles)

obtainable production between downtimes for redressing. In the charts, Figs. 3 and 4, the lengths of the bars are inversely indicative of the useful life of the electrodes. Again the radius- and near-radius-faced electrodes, AW-1875, AW-1878, AW-1879 and AW-1874, and the blunter-nosed electrodes, AW-1872 and AW-1873, exhibit a marked superiority over the sharper-nosed designs. The large increase in face area of the AW-1874 design is not considered too significant because of the comparatively small initial diameter of the welding flat. No data on increased area are presented for AW-1875, AW-1878 and AW-1879 because the work contact area is not conveniently commensurable. These electrodes still exhibited a definite radius after the welding tests.

An interesting and significant analysis can be made by listing the electrodes in the order of their performance characteristics, arbitrarily assigning unweighted point values to their respective positions and computing point totals. This analysis is shown in Table 6. The lower point totals indicate the better performance characteristics and clearly show the superiority of the radius-faced and blunt-nosed electrodes.

The extent of oxidation of the electrode nose provides a definite indication of the efficiency of cooling. The fluted electrodes with their shorter nose length show less oxidation, hence better cooling, and of those the designs with greater masses of metal at or near the welding face are superior in cooling efficiency.

A visual comparison of the electrodes after 10,000 spot welds under conditions in tests 1 and 2 is afforded by Figs. 5 and 6, respectively. The effects of the welding operations can be observed in the disturbance of metal and the mushrooming of the welding face. For convenient comparison

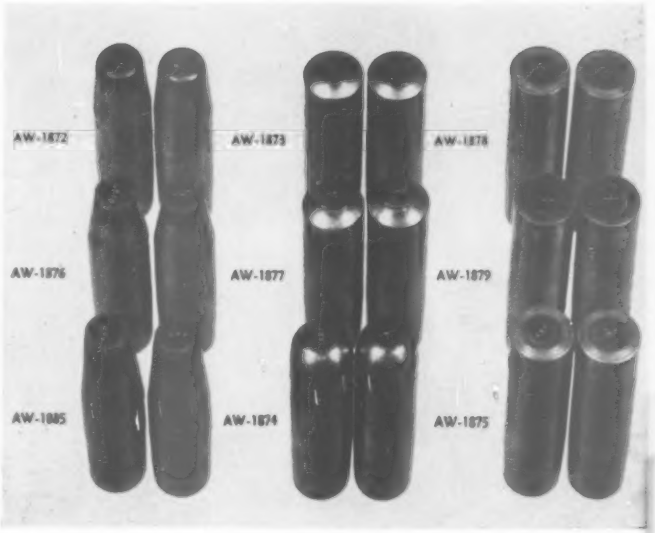


Fig. 5 Appearance of test electrodes after 10,000 spot welds in Test 1 (Weld Time—8 Cycles)

Table 6—Electrode Performance Analysis

	Designs Listed in Order of Decreasing Superiority					
	Maintenance of original face area		*Retention of face hardness*		*Retention of length*	
Order	*Electrode*	*Point value*	*Electrode*	*Point value*	*Electrode*	*Point value*
			Test 1			
1	AW-1875	2	AW-1875	1	AW-1875	1½
2	AW-1878	2	AW-1878	2	AW-1879	1½
3	AW-1879	2	AW-1874	3	AW-1878	3
4	AW-1872	4	AW-1873	4	AW-1872	4
5	AW-1873	5	AW-1879	5	AW-1874	5
6	AW-1876	6	AW-1877	6	AW-1876	6
7	AW-1877	7	AW-1872	7	AW-1873	7
8	AW-1885	8	AW-1876	8	AW-1877	8
9	AW-1874	9	AW-1885	9	AW-1885	9
			Test 2			
1	AW-1875	2	AW-1875	1	AW-1875	2
2	AW-1878	2	AW-1878	2	AW-1878	2
3	AW-1879	2	AW-1879	3	AW-1879	2
4	AW-1872	4	AW-1874	4	AW-1872	4
5	AW-1873	5	AW-1877	5	AW-1874	5
6	AW-1876	6	AW-1873	6	AW-1873	6
7	AW-1877	7	AW-1872	7	AW-1876	7
8	AW-1885	8	AW-1876	8	AW-1877	8
9	AW-1874	9	AW-1885	9	AW-1885	9

Summary

			Point totals		
Order	*Electrode*	*Description*	*Test 1*	*Test 2*	*Total*
1	AW-1875	2 in. radius	4½	5	9½
2	AW-1878	3 in. radius	7	6	13
3	AW-1879	10 in. radius, 4-degree angle	8½	7	15½
4	AW-1872	Pointed-blunt	15	15	30
5	AW-1873	30-degree truncated cone	16	17	33
6	AW-1874	Dome	17	18	35
7	AW-1876	Modified-pointed	20	21	41
8	AW-1877	45-degree truncated cone	21	20	41
9	AW-1885	Standard pointed	26	26	52

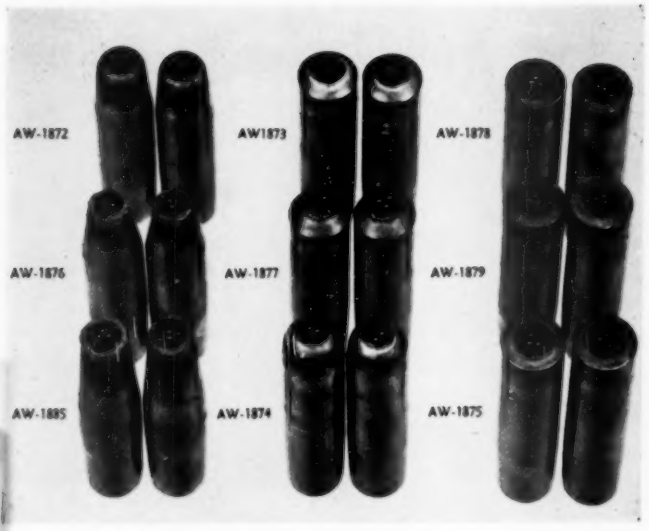


Fig. 6 Appearance of test electrodes after 10,000 spot welds in Test 2 (Weld Time—25 Cycles)

the electrodes were arranged in the following groups:

(*a*) Left Group: pointed noses.
(*b*) Center Group: truncated cone and dome noses.
(*c*) Right Group: radius-faced electrodes.

A comparison of the two figures clearly shows the deleterious effect of the longer weld time used in Test 2. In Fig. 6, a much greater degree of mushrooming and a greater extent of oxidation are apparent, while in Fig. 5 the electrodes are still relatively bright and clean and some welding faces are barely disturbed.

SUMMARY AND CONCLUSIONS

A series of tests were conducted to show the effect of nose design upon the performance and life of spot-welding electrodes. Although limited in scope, the tests showed a definite trend in favor of radius-faced electrodes. These electrodes gave the best combination of weld consistency and quality, useful life between redressings and total electrode life. Of the three designs AW-1875, AW-1878 and AW-1879, the latter appears the least useful because its comparatively complex welding face could not be easily redressed to the original contour without removing the electrode from the welding machine. The other two designs are easily redressed with simple tools and with a minimum of metal removal.

Closely following the radius-faced electrodes in performance are the relatively blunt-nosed designs AW-1872, AW-1873 and AW-1874. These electrodes are quite easily dressed in position, and with their high resistance to mushrooming also require little metal removal.

The more pointed nose designs, and especially AW-1885, suffer by comparison. Although producing consistent welds within the scope of this investigation, these electrodes deteriorated much more rapidly, thereby indicating reduced life between necessarily more frequent dressings, increased machine downtime and shorter total electrode life. It can safely be conjectured that these electrodes could not have produced many more welds without serious effects on weld quality. The extremely pointed nose is often used for greater electrode-work clearance, frequently unnecessary. Greater economy of production might be effected by a minor redesign of parts to provide slightly more clearance or overlap so that sturdier, longer-lived electrodes could be used.

For maximum benefit from properly designed electrodes, production plants must assure themselves that the electrodes are properly used and maintained. An operator training program on electrodes alone would soon pay for itself in better welds and increased production.

ACKNOWLEDGMENT

The authors wish to acknowledge the invaluable assistance of C. N. Pfaffenberger, who conducted much of the experimental work disclosed herein.

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(*Continued on page 414*)

Welding Characteristics of Materials for Aircraft Gas Turbines

Results of a welding program on sheet materials which can retain their strength at the high temperatures used in gas turbines

by A. J. Rosenberg

INTRODUCTION

AIRCRAFT gas turbines continually require materials which can retain their strength over a wide range of temperatures. At the same time, strength-to-weight ratios should be high, critical alloy content should be low and high quality welding must be practical.

Several years ago the General Electric Co. initiated a formal welding program which was to include the various sheet materials that prove useful for jet engines.

AUSTENITIC STAINLESS STEELS

One of the most immediate problems to face us was a substitution program for the columbium-stabilized stainless steel, Type 347.

There is no doubt that 347 is readily welded by the common welding processes: the metal arc, inert arc, atomic hydrogen and the various resistance welding methods. Brief welding tests were conducted on 347 with tantalum-columbium added for stabilization rather than the straight columbium, and no differences in welding were observed. In the case of 321, however, with titanium added for stabilization, several differences are worthy of note. Where inert arc, metal arc or resistance welding is concerned there are no significant differences between 321 and 347. But it has been our experience that the reaction when utilizing the atomic hydrogen process is such that a scum may form on the molten pool which makes welding difficult. And in addition, we have encountered weld porosity in many 321 atomic welds. This skin effect and porosity condition was noticeable even in extremely thin sheet, and the process is avoided wherever possible.

In the case of metal arc welding of 321, we have been employing 347 electrodes. The activity of the titanium has made its transfer across the arc a rather difficult problem and no 321 electrode is manufactured today. Several tests have been conducted comparing the effectiveness of other electrodes with 347 for the welding of the 321, and it does appear possible that substitutions may be made in many instances. Strengthwise, built-up welds with straight 18 and 8 weld metal, or 18 and 8 with extra low carbon, or Type 316, are all satisfactory. Failure of the joint will always take place outside of the built-up section. However, if the welds are ground flush to give a more accurate measure of weld strength the failures take place at the weld. Even under these conditions the mechanical properties of the joints were still comparable to the parent metal. So that, by far the most serious difference with these various electrodes is their susceptibility to corrosion. Welds sensitized for two hours at 1200° F. were subjected to a 72-hr. Strauss test with the following results: In the following few photographs, 321 is the base material. Figure 1 was made with a 347 electrode. The 347 was attacked to a depth of approximately 0.002 to 0.004 in. Figure 2 is a sample welded with 316 which was about the same. Figure 3 was with a 308 electrode and the 308 suffered general corrosion over the entire bead and complete corrosion through the fusion line. Figure 4 was made with the 308 extra low carbon and it compared favorably with the 347 and has warranted the initiation of further more stringent testing.

Based on our 321 experience, we have substituted the material for 347 in most of our applications. In those instances where 321 could not attain a high enough strength at the operating temperatures involved, the use of Timken Alloy 16Cr–25Ni–6Mo in sheet form was recommended and tests were conducted on this material in various conditions of cold work. Timken is readily welded by the common methods, and can be welded to 347 or 321 as well as to itself. In metal arc welding we are employing a heavily coated Timken electrode with good results. One note of caution should be injected concerning the handling of Timken—that is to realize that the material is not stabilized and con-

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Paper was presented at the Thirty-Second Annual Meeting, AWS, Detroit, Mich., week of Oct. 15, 1951.

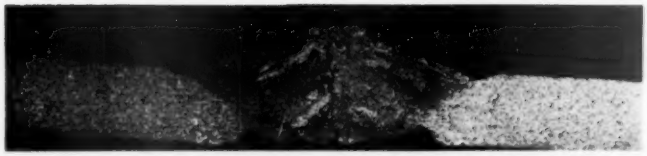


Fig. 1 Type 347 Welding Electrode. Approximately 0.002 to 0.004 in. depth of attack following sensitizing and 72 hour Strauss test

sequently subject to intergranular attack after heating in the 1000 to 1600° F. range.

One important point with all of these austenitic stainless steels that attain maximum properties through cold working is that welding results in a fully annealed cast structure, and joint strength is therefore limited to that of the annealed material.

Fig. 2 Type 316 Welding Electrode. Approximately 0.002 to 0.004 in. depth of attack following sensitizing and 72 hour Strauss test

AGE-HARDENABLE ALLOYS

One of the most promising high-temperature alloys that does not depend on working for the attainment of its high strength level is the age-hardenable material, Inconel "W." Inconel "X," a later alloy development, with slightly improved mechanical properties brought about through the addition of 1% columbium, is less desirable from the critical alloy standpoint, but as far as welding techniques are concerned, the two materials may be considered the same. Both materials can be successfully resistance and arc welded if certain precautions are observed. Excellent tensile shear results can be obtained at several conventional austenitic stainless steel spot weld settings with normal electrode forces, but under those conditions the material has a tendency toward weld porosity or dendritic shrinkage. The defect, evident in both X-ray and etched cross sections is shown here.

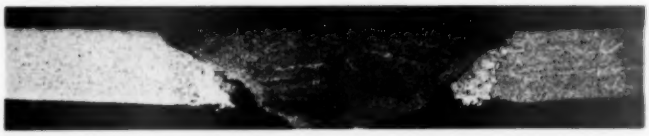


Fig. 3 Type 308 Welding Electrode. General corrosion over entire weld and complete corrosion through the fusion line following sensitizing and 72 hour Strauss test

Fig. 4 Type 308 ELC Welding Electrode. Approximately 0.002 to 0.004 in. depth of attack following sensitizing and 72 hour Strauss test

Fig. 5 Tensile shear sample of spot weld in Inconel "W" failing in base metal. Note internal weld defect

Figure 5 is a sample that was subjected to tensile shear tests showing failure in the base metal. It indicates that the defect is not serious from a strength standpoint, and fatigue testing shows that it is not important there, but a sound weld was the objective for air force parts and further tests were conducted. We found that the defect could be minimized by (1) slow weld cooling, (2) high unit forces or (3) a combination of both.

Slow weld cooling could be accomplished through the use of a relatively low current over a long period

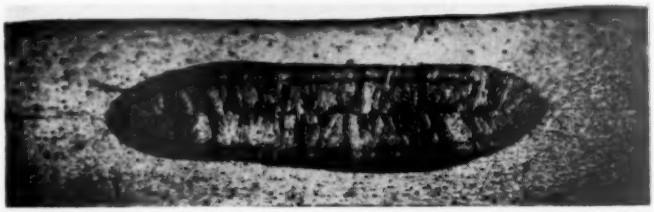


Fig. 6 Sound spot weld in 1/10-in. Inconel "W"

of time, with as many as 48 weld pulsations. But while such a setting did result in sound welds, the weld time involved is impractical from a production standpoint.

High unit forces were attained through the use of flat-tipped electrode with chamfered sides, but plate separation became excessive and distortion was increased. The most satisfactory solution, then, was a compromise condition. Through the use of medium or low conductivity electrodes, pulsation welding and high machine forces, all contributing factors were taken into account and the sound weld shown in Fig. 6 was achieved. The electrode forces involved with these materials ranged from 2500 lb. for 0.045-in. stock to 4500 lb. for 0.094-in. stock. And it is our opinion that forces of these magnitudes will become more common with the high-temperature alloys.

Occasionally coring was observed around the edges of these welds, but coring is not a defect and is usually associated with high electrode force, especially with nickel alloys. As with spot welding, Inconel "W" has a tendency toward internal defects in the weld when seam welded. Since seam welding wheels are cooled by a direct stream of water, it is impossible to effect drastically slow cooling but slow welding speeds are helpful and advantage should certainly be taken of the high forces necessary.

No particular difficulties were encountered in inert arc welding the material, provided good metal backing or inert gas backing was employed. Welds so made satisfactorily met bend test requirements in both the as-welded and age-hardened conditions. Where short time properties of these welds were concerned, a direct age after welding at 1300° F. produced joint strengths comparable to the parent metal, but when stress rupture is taken into account this heat treatment results in joints of approximately half the parent metal strengths. By treating at a higher temperature of 1450° for 2 hr., these stress rupture values can be increased considerably, although short-time properties are reduced slightly. We recommend the 1450° treatment on our fabrications. These improvements in strength can also be realized for spot welds. In one test a single 1300° F. aged spot in 0.045-in. Inconel "W" failed at 370 lb., while a similar spot treated at 1450° F. failed at over 600 lb.

Metal arc welding presents several difficulties with

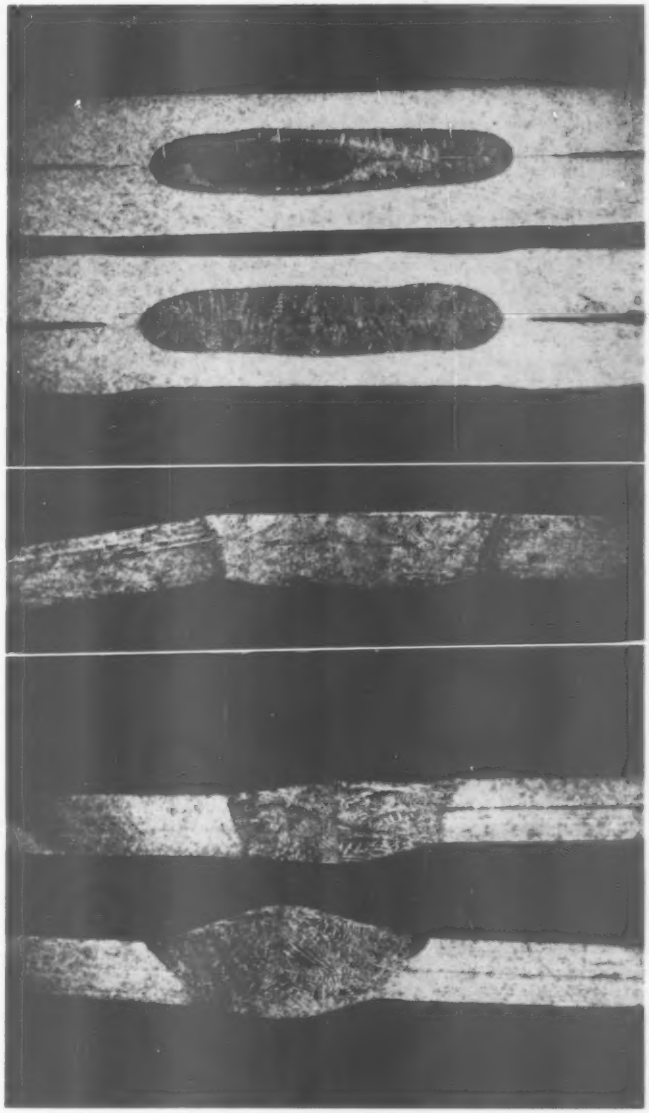


Fig. 7 Welds in Haynes Stellite Alloy No. 25

A. Seam weld
B. Spot weld
C. Atomic hydrogen
D. Inert arc weld
E. Metal arc weld

this material. Two coated electrodes were tested. These included an Inconel electrode, and an Inconel "X" electrode. The Inconel electrodes are produced particularly for the welding of straight Inconel, but they show a reasonable response to age hardening when used with Inconel "W" because of dilution with the base metal. However, the Inconel "X" electrode has a composition corresponding to Inconel "X" and responds to age hardening without the need for dilution. Short-time tensile strengths with the "X" electrode were 25,000 to 30,000 psi. greater than the straight Inconel electrodes and more nearly comparable to the aged parent metal. However, slag removal is a definite problem. The slag with the regular Inconel electrodes never approached the ease of removal associated with austenitic stainless steel electrodes, and the removal with the "X" electrode is even more difficult. We were warned that the slag must be removed for high temperature operations, so that hand benching will probably be necessary, unless the straight Inconel electrode is satisfactory. Another difficulty with the Inconel "X" electrode is its high electrical resistivity which causes the wire to overheat when welding at normal currents. To overcome this it is necessary to use short lengths of electrodes and to keep current at a minimum.

HIGH-TEMPERATURE ALLOYS

For higher temperature service several Haynes Stellite Alloys have been suggested. One of these is the Alloy 25. This particular material is one of the most readily welded of the new materials tested. Metal arc welding with 25 electrodes, inert arc welding and resistance welding presented no particular difficulty. Sound welds by all these processes are shown in Fig. 7. Inert and metal arc joints approached the strengths of the parent metal, and resistance welds were sound and ductile. Several forming and machining problems were encountered with this alloy, but those are beyond the scope of this paper. A second Haynes Stellite Alloy, Alloy 88, has not faired as well. The material inert arc welds satisfactorily, although the joint loses some of its coldworked strength, but it has been impossible so far to obtain completely crack-free welds with the electrodes employed. HS-88 is a 12% chromium, 15% nickel alloy with 0.11% boron—the boron may account for the cracking tendency, although we have not completely given up on the possibilities of successfully welding this material, and further testing is under way.

LOW ALLOYS

For applications in the lower temperature ranges, say up to 800° F. we have substituted the low-alloy high-tensile steels for the previously used stainless steels. Currently, NAX is being employed but several other materials are under consideration.

NAX, YOLOY, CORTEN, NES-70, RDS-50, 8615, to mention a few, can all be resistance welded, but with the exception of YOLOY, a stress relief or temper is absolutely essential. In the case of NAX, the rapid cooling associated with spot welding resulted in a martensitic formation that could only be changed by subsequent heat treatments. Hardness in the weld prior to these treatments reached a Rockwell C of 50. A current flow less than the initial amount applied before a complete cooling of the weld, but after the martensite had been formed, could reduce this hardness markedly. However, if the tempering pulse was too high, martensite reformed on cooling and if the tempering pulse was too low it had no effect. Tempering with a post heating cycle on the spot-welding machine is extremely helpful, but this should be used in addition to furnace stress relieving and not in place of it.

No tempering is possible with the machine during seam welding, and all seam welds had to be furnace annealed to reduce hardness and increase ductility. Welds made under identical conditions are shown in Fig. 8. Samples on the left were not annealed, while those on the right were. The differences in peel tests are apparent. Weld hardness was reduced from 43 Rockwell C to 23.

Metal arc welding is no more of a problem with these low-alloy steels than it is with plain low-carbon steels with the exception of the need for stress relief. Inert arc welding, however, presents individual problems. Although NAX is fully killed, porosity was detected in x-rays on almost all inert arc welds. The condition was somewhat improved when short arc lengths and slow welding speeds were maintained, but the condition was never entirely eliminated and must be recognized as a limitation.

YOLOY is a rimmed steel and the porosity encountered there was so excessive that we do not recommend the process with this material for high quality applications.

The use of Corten, another low-alloy high-tensile material, was also discouraged—this time because of the wide chemical variations allowed by the manufacturer and its effects on low-temperature impact strength and welding. Inert arc welds on two heats were low in ductility even after stress relief and they all contained varying amounts of porosity. Limited tests on the other low-alloy materials indicate that they can all be successfully resistance welded and inert arc welded provided small amounts of porosity are permissible. Limited inert-arc-welding tests were made welding one low alloy to another, and it is interesting to note that the excessive porosity encountered with YOLOY was reduced when this material was welded to the killed or semi-killed alloys.

Limited tests have been conducted on 4130 sheet material. The sheet material was successfully spot welded but once again, a stress relief was necessary to obtain weld ductility. In the case of inert arc welding, however, cracking was a problem. If the sheet material was welded cold, fine transverse cracks were observed in the weld. Using a 600° F. preheat,

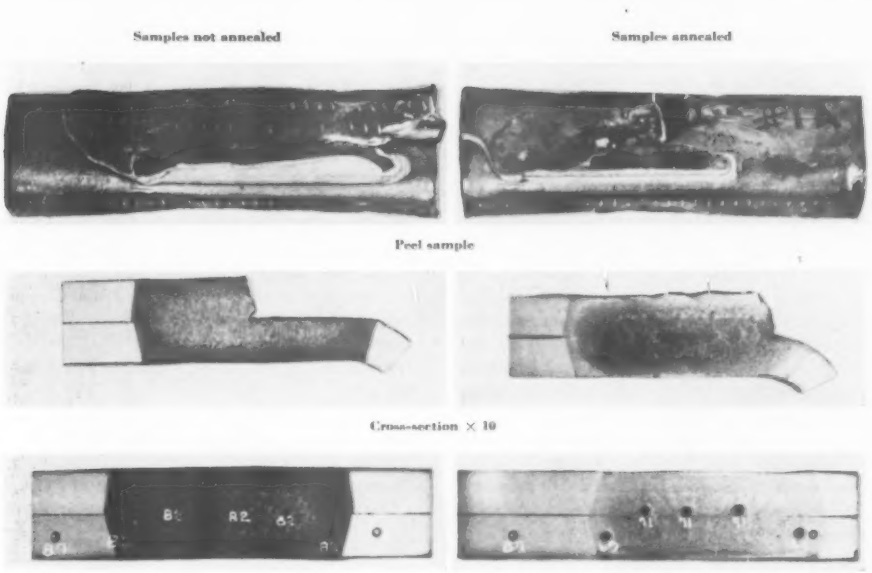

Samples not annealed
Samples annealed
Peel sample
Cross-section × 10
Hardness survey *
*Rockwell superficial. Weld 15 n. Base metal, 15 t
Seam welds in NAX made at the same weld settings showing the great decrease in hardness and brittleness after a stress-relief anneal

Fig. 8 Effect of 1150° F. anneal on seam welding NAX

and again inert arc welding, once more resulted in the same type of cracks, although weld hardness was reduced from approximately 50 Rockwell C to 30. A postheat, for 15 to 20 min. at 600° F. immediately after welding, as well as the preheat completely eliminated these cracks on all the samples, made under otherwise identical conditions. So that cooling rate is obviously a deciding factor.

TITANIUM

Recently a growing interest in titanium and titanium alloys has been noted throughout the industry. The strength-to-weight advantage of these materials over aluminum and steel and the possibilities of tremendous weight savings on applications below 800° F. have led us into extensive investigations. Just as the various alloys I have been discussing must be evaluated in individual groupings so must the titanium alloys be considered on individual group merits. There are now available at least seven different alloy grades of titanium with strengths ranging fron 75,000 to 175,000 psi. and with corresponding elongations from 25% down to 10%.

For the purposes of this paper, I have conveniently separated these materials into three groupings which we have found useful. There is the low strength, unalloyed commercially pure grade of titanium. There is the oxygen-nitrogen and carbon alloys which may be considered as low-strength alloy materials, and there are what we consider the high-strength alloys, containing oxygen, chromium and iron, or manganese-aluminum.

Because of the marked affinity of titanium for oxygen, hydrogen and even nitrogen at temperatures above 1000° F. the material must be protected from their deleterious effects during welding. This means that only the inert arc process is practical of all the available gas and arc processes, and even with the inert arc extreme care must be taken to assure adequate gas coverage of the molten weld surface and protection of the weld underside. Tight metal backing, or preferably, inert gas backing is required. Adequate coverage is indicated by a bright, clean, shiny surface. It was determined that slower welding speeds resulted in much better gas coverage and less surface oxidation. With 0.094-in. material, welding at 27 in. per minute, a light grey oxide film was present while at 4 in. per minute a shiny violet surface resulted. A further improvement in coverage can be achieved by attaching a nonconducting strip to the inert arc torch nozzle and using the strip as a cover to retain the inert gas over the molten pool. While no difference in ductility was noticed for commercially pure grades welded under any of these conditions, the most effective gas coverage should be used as a safeguard against contamination.

In the case of the commercially pure materials, inert arc weld strength and ductility is comparable to the parent metal when these precautions are observed. For the oxygen-nitrogen and carbon alloy, welding will still result in a joint comparable to the parent

metal provided the carbon content remains below 0.25%. But in the case of the higher strength alloys, there is a marked loss in ductility following welding. Inert arc welds with these high-alloy materials appear excellent, but the welds are so brittle that several samples cracked across the weld during handling, and further cracking took place during subsequent shearing operations. Although tensile strengths were at a high enough level (149,000 psi. at room temperature) elongations were as low as 5% and all failures took place in a brittle manner through the weld.

Several samples of parent metal of these high-alloy titanium were subjected to heating and cooling cycles in a vacuum in an effort to determine their effects on ductility. Prior to heating, these strips could be bent a full 180° about a $1^1/_2$ T radius without failure. Heating and cooling to 1800° F. in a vacuum reduced this angle to 50°, and if the cooling was done in air, the bend angle was even further reduced. Time at temperature was also a factor, so that it seems apparent that recrystallization, grain growth, and contamination are all factors contributing to low weld ductility. Experience indicates that recrystallization and rapid grain growth are initiated at approximately 1600° F.

Figure 9 shows a panorama from the parent metal to the weld zone for a weld in high-alloy titanium, Ti150A. You can clearly observe the change from the hot-rolled, annealed parent metal to the structure at the transition zone where recrystallization and the start of grain growth is noted, to the massive grains with their random orientation at the weld.

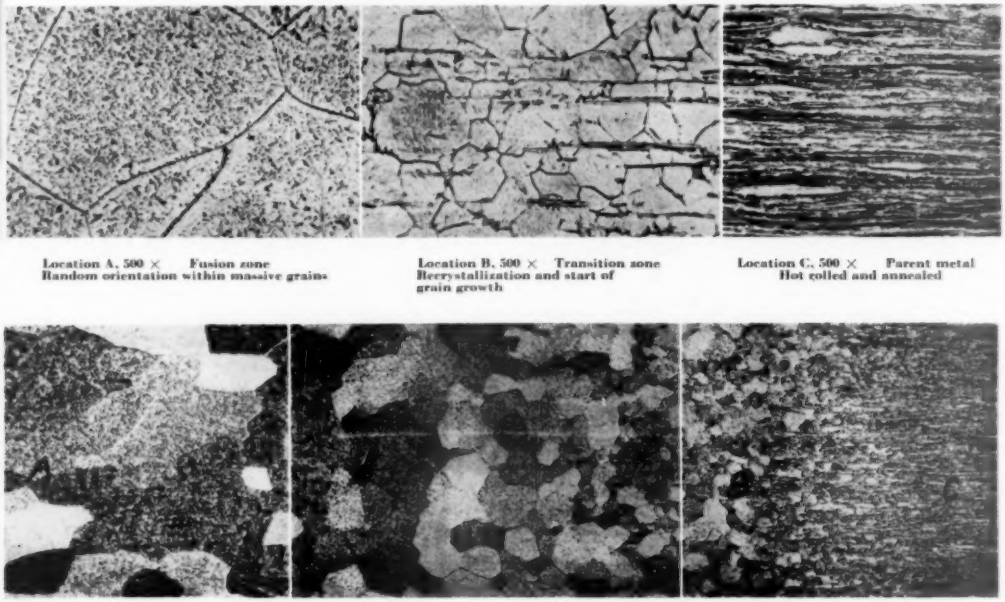
Similar grain growth can be observed in lower alloy welds, but the lower alloy parent metal is more ductile to begin with than either of these so that grain size did not reduce bend ductility as severely.

As far as spot welding is concerned, sound spots can be obtained in titanium alloys over a wide range of machine settings, and tensile shear strengths are comparable to other materials of comparable strengths. But ductility is low with the high-alloy material.

Commercially pure titanium that has been spot welded will fail by tearing the base metal; the oxygen-nitrogen and carbon alloy will also fail in a ductile manner, but RC-139-A, the high alloy, has its ductility drastically reduced by welding and failures are extremely brittle and occur abruptly during tensile shear tests.

In general, flash welding results in a more ductile structure than either inert arc or resistance welding because of the forging action and inherent grain refinement. Flash welding of titanium can best be accomplished by machines which facilitate rapid push-up and burn-off to prevent excessive oxidation. To date it appears that most of the titanium alloys can be successfully flash welded and retain a considerable degree of ductility. In the case of the higher alloy materials, it may be the only feasible method of joining.

While this paper has not attempted to go into too many details of the actual testing involved, the weld settings employed or the strengths of the joints, you can perhaps get some idea of the magnitude of our



Location A, 500 × Fusion zone
Random orientation within massive grains

Location B, 500 × Transition zone
Recrystallization and start of grain growth

Location C, 500 × Parent metal
Hot rolled and annealed

Fig. 9 Panorama at 100 × from weld zone to parent metal

welding program. It is our objective to get the necessary welding facts together in order that better engines may be built which require fewer of the world's strategically scarce materials.

Dilution and Diffusion Aspects of Nonfusion Welding

Discussion by H. Udin

It is always gratifying to find educational papers in THE WELDING JOURNAL; particularly those, such as the one by R. D. Wasserman and J. Quaas, that discuss the frontiers of the sciences and technologies pertinent to welding. However, I must take issue with several points in this paper.

The authors discuss the deleterious effects of dilution versus diffusion and conclude that the former is more harmful because it may result in formation of brittle intermetallic compounds in the filler alloy layer. However, diffusion into the solid base metal also can, and does, result in the formation of brittle phases. To take an extreme example, suppose copper were to be joined with liquid zinc at 850° F. The filler layer would be diluted only to the extent of dissolving some 2% of copper. Metallographically it would show eta phase with a small quantity of epsilon precipitate. The copper, on the other hand, would exhibit successive diffusion layers of epsilon, gamma and beta brass, all extremely brittle phases. In general we will find in the diffusion zone every solid phase that can form between the base metal and the filler alloy at the brazing temperature. Thus to minimize this zone low diffusibilities and short times at temperature are desired.

Another concept with which I disagree is that diffusion is somehow necessary for metallic bonding in subfusion joining. This is one of a pair of misconceptions under which our cousins, the powder metallurgists, labored for a good many years, and from which they are just now shaking loose.* We all realize that a clean grain boundary, whether interphase or intraphase, is as strong or stronger than the grains themselves. To form such a boundary between two bodies of metal we must merely bring their surface atoms as close together as the interior atoms. This means (1) removing all foreign molecules from the surfaces, and (2) eliminating down to an atomic scale all surface asperities. While both of these things can be accomplished by diffusion, they can also be done in other ways, so the diffusion process is not necessary for bonding. In brazing, the second point is no problem, since the liquid filler alloy easily conforms to the asperities of the solid substrate. Foreign molecules are generally dissolved in a flux. Then if the interfacial tension relationships among flux, filler, and substrate are correct, the filler alloy displaces the flux and wets the substrate. The net result is an array, at room temperature, of clean, strong interphase grain boundaries, yet no part of the process has depended in any way on diffusion. The diffusion that does occur during brazing is merely the inevitable result of bringing together at elevated temperature two mutually unsaturated phases.

Finally we come to the interrelationships among dilution, joint thickness and joint strength. The apparent high tensile strength of the filler alloy is attributed by the authors to dilution. A corollary assumption is that the thinner the joint, the more dilution occurs. Undoubtedly during the copper-base brazing of steel the filler alloy is strengthened somewhat by dissolution of iron. However the classic experiment of joint tensile strength versus joint thickness was performed on silver solder joints in stainless steel. The solubility of stainless steel constituents in silver solder at silver soldering temperature is so limited that it cannot account even for the apparent strength increase, let alone accounting for the dependence on joint thickness.

Actually, there are two mechanical effects in a thin joint that in most cases far overshadow the chemical effect of dilution. Both stem from the inhibition of plastic flow in the joint. First, it must be recalled that an all-filler-metal tensile specimen can neck freely, whereas only limited necking occurs in the brazed joint. The engineering tensile strength of the filler alloy—maximum load divided by original cross-section area—bears no necessary relationship to the tensile stress at fracture of either the all-filler specimen or the brazed joint. If we plot the *true fracture stress* of the brazed joint against joint thickness and compare the plot to the *true tensile strength*—load at fracture over necked area—of the filler alloy, much of the difference disappears.

H. Udin, Massachusetts Institute of Technology, Cambridge, Mass.

Paper by R. D. Wasserman and J. Quaas was published in the December 1951 issue of THE WELDING JOURNAL, pp. 1098–1101.

* The companion misconception, also extending into the field of joining, is that recrystallization across the boundary is somehow necessary for a good solid-state bond.

The rest of the strengthening is due to the stress pattern in the joint when it is under tension. When the yield strength of the filler alloy is reached it starts to extend. To do so it must, of course, reduce in area so as to maintain a constant volume. The stronger base metal resists reduction in area, and the result is a shear stress across the interface. This puts the base metal side of the interface into radial and circumferential compression, and the filler metal side into tension. With increasing load, as the axial tensile strain increases, the resolved shear stress on the base metal side of the interface increases more than proportionally; that on the filler metal side increases less than proportionally. In a sense we can say that the strong base metal supports the weaker filler metal. This triaxiality diminishes as we move away from the interface, so, the thinner the joint, the stronger it will be. It is interesting to note that (1) the heat-affected zone in aluminum weldments aged before joining shows the same effect; the thinner the zone, the higher the transverse tensile strength. (2) Plastic cemented joints in metals behave the same way.

The authors have made a transposition in defining the factors of the Dushman-Langmuir equation. h is Planck's constant of action, in gram-calorie-seconds. If Q is defined as the activation energy (not dislocation energy, which is another animal altogether) per gram atom, as the authors use it, then N must be defined as Avagadro's number rather than Loschmidt's number. It is interesting that Q/Nh has the dimensions of frequency. The Dushman-Langmuir equation is obsolete as a research tool, but we can obtain from it a good physical conception of the diffusion process. The frequency part of the coefficient is related to the number of times an atom tries to move, while the exponential defines the probability that it will possess enough energy to do so.

Authors' Reply

We are extremely gratified that our paper on "Dilution and Diffusion Aspects of Nonfusion Welding" has aroused interest as evidenced by Prof. Udin's discussion.

The authors agree with the discusser in that diffusion into the solid base metal can also form brittle phases, such as occurs when dilution takes place. However, we prefer a diffusion process rather than one of dilution for various reasons. Our experiences have evidenced that, quantitatively, the diffusion process compared with that of dilution can be better controlled by maintaining specific conditions during the joining operation. By contemplating possible alloy combinations which might form during a joining or bonding operation, we can introduce other metallic molecules which would reduce or accelerate diffusion, providing the choice of the foreign molecule is compatible with the resultant alloy system.

The authors, to their knowledge, did not construe the concept that diffusion is necessary for bonding. We did stress strongly the attributes which were imparted to a joinment by the diffusion of specific metallic atoms purposely introduced into the resultant alloy combination. Thus, our paper divulged only the basic facts which we consider important when developing new filler metals, particularly those used below the fusion temperature. We did not discuss the process of joining with the filler materials which were presented in the discussion. We do, however, agree with the discusser that the aspects he has presented are undoubtedly functional in the mechanics of accomplishing a brazed joint.

We concur wholeheartedly with Prof. Udin's discussion of the geometry of joints used in specimens prepared for investigating mechanical properties. Not only do we have the classic examples of tensile strength versus joint thickness which were obtained from specimens employing silver solder joints on stainless, but also the differences encountered in results of many tests utilizing any alloy for test purposes, comparing 0.505-in. specimens versus 0.250-in. or even 0.125-in. specimens taken from the same joinment or weldment. The authors did try to define the importance of dilution and diffusion in respect to their effect on mechanical properties.

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(*Continued on page 422*)

Remove Buttonhead Rivets with Your Blowpipe

Cutting blowpipe or attachment is useful tool in all shops

by D. T. Kelley

BUTTONHEAD rivets can be easily and quickly removed with your cutting attachment or cutting blowpipe. The trick in removing them is to cut a slot in the rivet head, and then cut away each half of the rivet separately.

D. T. Kelley is connected with The Linde Air Products Co., Newark, N. J.

Fig. 1 Heating the buttonhead rivet is the first step in removing it. Only the preheat flames are used, and the heating job takes about one minute

Fig. 2 The operator is now cutting the slot. The nozzle is being held about one and a half inches from the rivet head. Press down the cutting-oxygen lever slowly

The rivet head is heated to a dark red. Use only the preheat flames, and point the flames directly at the rivet head. Then, holding the nozzle parallel with the sheet or plate, aim the preheat flames at the center of the rivet head and slowly press down the cutting-oxygen lever. This will slot the rivet head so that it will look like a roundhead screw. As the slot is completed, swing the nozzle in a small curve either to the right or left and cut away half of the rivet. Then swing back

Fig. 3 This sketch shows the slot cut in the rivet head and the two remaining sections that are cut away

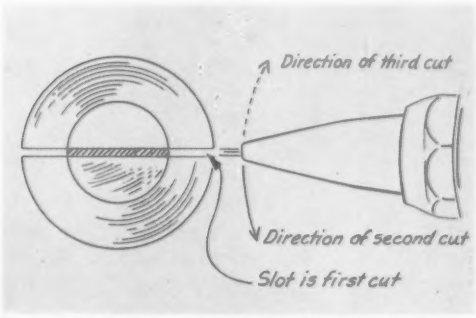

Fig. 4 The rivet now can be knocked out of the hole with a hammer and punch. The blowpipe should not be used as a hammer on jobs like this

and cut away the other half. Then knock the rivet out with a hammer and punch. Do not use the blowpipe as a hammer because a blow might spring the tubes or damage the nozzle.

With a cutting blowpipe or cutting attachment straight lines, circles or irregular shapes are easy to cut and scrap metal can be cut up for the scrapyard.

Production Rebuilding of Tractor Rolls by Submerged-Arc Welding

WITH the aid of a special work positioner and a Unionmelt welding machine, the Alloy Hard-Facing Co., of Minneapolis, Minn., is able to rebuild worn-out tractor rolls in a fraction of the time usually required. The rolls are mounted on an axle placed in a welding positioner, which rotates the rolls at the proper speed for welding. The Unionmelt welding machine runs on a track above and parallel to the axle. In making the buildup, weld metal from a high-carbon rod is deposited on the roll surface to a depth of $^3/_8$ in. in three overlays. As the roll completes each revolution, the welding machine is advanced a small distance laterally so that flat overlapping beads are produced across the face of the roll.

In this submerged-arc welding operation, the granulated Unionmelt welding composition is automatically laid down on the work ahead of the welding rod. High-carbon rod (Oxweld No. 296), $^5/_{32}$ in. in diameter, is fed automatically to the welding zone from a coil by the type UE welding head. Welding takes place quietly beneath the welding composition, without flash, glare or spatter, and it is unnecessary for the operator to wear goggles or a welding hood. (In Fig.1, the operator is wearing a plastic safety mask, in accordance with his company's general safety rules.) On cooling, the fused composition snaps off by itself, or may be removed by tapping with a hammer. The welds are smooth enough so that no further finishing is required for this application.

The tractor rolls are $8^1/_2$ in. in diameter and are welded at a speed of about 30 in. per minute produced by turning the rolls at about 1 rpm. Welding current is 300 to 325 amp. at 25 v.

Tractor idler rolls are also rebuilt in this way, using similar welding materials and conditions. In reclaiming idler rolls, the sides of the center ridge are rebuilt by manual arc after the two faces have been rebuilt by submerged-arc welding.

The surfaces of the rolls and idlers when rebuilt by this method have a normal hardness range of 200 to 275 Brinell. In use, this deposit work-hardens with typical deposits attaining a hardness of 325 Brinell.

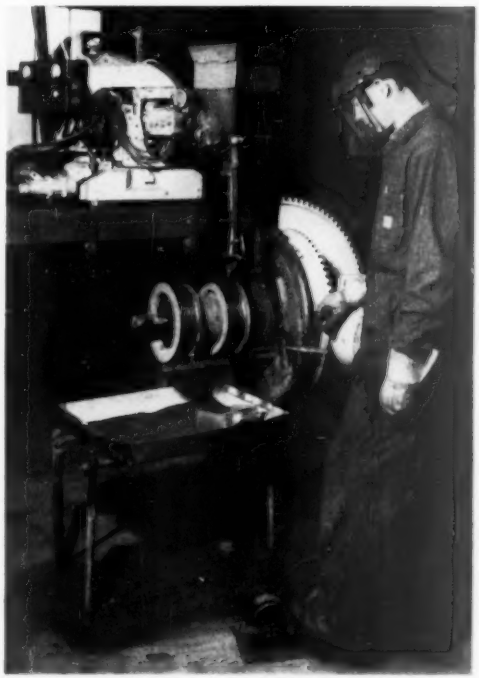

Fig. 1 Salvaging of tractor rollers by submerged-arc welding

Under normal conditions, one face of the $8^1/_2$-in. diameter roller can be rebuilt in about 40 minutes. In a well-planned installation, it is possible to reduce the set-up time proportionately by mounting from 5 to 8 rollers on one axle.

Hints on Radiant Heating

Welded joints make strong, leakproof system

by R. G. Harner

USES for radiant heating have almost no limit. It is used to heat shops, garages, industrial buildings, homes, schools, hospitals, and farm buildings. Radiant systems are even used to remove snow from driveways, roads and sidewalks.

Radiant heating really is not new. It is simply another method of using hot water for heating purposes. Pipe coils are placed in the floor, ceiling or walls to replace conventional radiators. The coils can be placed under almost any type of covering—wood, asphalt tile, rubber tile, linoleum, or concrete. Of course, the pipe or tubing joints must be tight and permanently leakproof because hot water flows through the pipes to furnish the heat.

Threaded, coupled, soldered or welded joints can be used to fabricate the pipe coils. However, welded joints are best because you get a strong, leakproof joint that will last as long as the pipe. Either welding or soldering, on jobs of this kind, is profitable work for any welding shop. When steel or wrought-iron pipe is used, joints can be welded as shown in Fig. 2. This is an ordinary pipe welding job.

R. G. Harner is connected with the Linde Air Products Co., Cleveland, Ohio.

WELDING HINTS

Here are a few things to remember when you weld small diameter pipe for radiant heating systems. Make sure the edges of both pieces have been cut square. Then clean the edges with a wire brush to remove rust, dirt, and slag. Thin-wall pipe needs no beveling. However, if the pipe wall is thicker than $^{3}/_{16}$ in., the edges should be beveled. When two pieces of beveled pipe are butted together there should be a vee of 60-to 90-degree between them.

Before you start to weld, line up the pipe. Use a length of angle iron or a pipe clamp if you have one. Leave about $^{1}/_{8}$ in. space between the ends, then make three or four tack-welds.

Start the final weld on the side of the pipe and move up to the top. Rotate the pipe so that the place where you stop is half-way between the top and the side. Then continue the weld. Be sure to melt the metal to the bottom of the vee. When you add molten welding rod to the puddle, keep the end of the rod in the puddle. Build up the weld until it is about $^{1}/_{16}$ in. higher than the surface of the pipe. Of course, it will be necessary to weld some joints in position and that calls for some overhead welding.

Fig. 1 The mechanics in this garage will be comfortable working under a car even in the coldest weather because the floor will be warm

Fig. 2 Oxyacetylene welded pipe joints are strong and leakproof. They will last as long as the building

Fig. 3 Copper tubing and solder-type fittings make leakproof radiant heating systems. The air-acetylene torch provides an instant, high heat

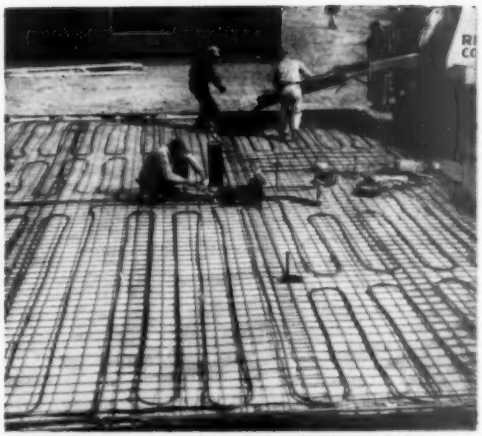

Fig. 4 Here, copper coils are being tied into a header on a heating system for a small home

SOLDER-TYPE FITTINGS

Copper tubing and solder-type fittings will make strong, leakproof piping systems, too. Here are some hints for doing this kind of job.

The tubing usually is laid out in a jig and formed. Then the inside of the fitting and the outside of the tubing are cleaned thoroughly with steel wool and painted with acid flux. The tubing is then inserted into the fitting and both heated with an air-acetylene torch. Play the flame over the joint with a brushing motion. Check the temperature by putting the solder to the heated spot. Don't overheat and don't put the flames near the solder when testing. When the joint is hot enough, take the flame away and touch the solder to the joint. The solder will melt and it will be drawn into the joint by capillary action. If the solder does not melt easily, heat the joint again and test with the solder. Clean off any flux that is left with a damp cloth.

Of course, all pipe work must conform to local code requirements and standards. And all radiant heating installations should be tested with water under pressure to be certain there will be no leaks in the piping systems. Design of a radiant system should be done by a heating engineer.

Heating Helps Shrink Stretched Metal

by W. Purcell

SHRINKING metal that has been stretched is another job for the heating blowpipe. It's a problem that auto body men come up against whenever metal has been so badly damaged that even restoring it to general shape still leaves a high or low spot in this damaged area. It cannot be hammered back into shape since there is no place for the stretched metal to go. The only answer to such a problem is shrinking the metal, which should be done after the bumping and before the finishing operation.

Shrinking stretched metal (1) is an operation that falls into five main steps, each one of which is fairly simple.

First, using an oxyacetylene blowpipe, heat a small spot $^3/_8$ in. in diameter in the center of the stretched panel to a cherry red color (2). The metal in this stretched area will thus expand while the spot itself will rise in a low peak. On a low crown panel that is only slightly stretched, a spot $^3/_{16}$ in. in diameter will be found large enough; never use a spot larger than $^1/_2$ in. in diameter. Don't melt a hole in the metal.

Fig. 1 Five main steps in shrinking stretched metal

Second, strike this heated area a hard blow with a hammer, driving it down (3). A dolly block should then be held quickly against the bottom of the resulting depression, employing outward pressure from the inside (4). Simultaneously, tap down the rim of the depression from the outside with the hammer.

In using a dolly block, make sure you employ a flat face under a low crown panel and a low crown face under a high crown panel. When smoothing the area, however, use a low crown face under low crown metal and a high crown face under high crown metal.

Finally, quench or chill an area about 6

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in. in diameter all around the spot, using a water-soaked sponge (5). A cellulose sponge is excellent for this purpose and this method is faster than that of air cooling and it lessens the possibility of over-shrinking. Care should be taken throughout the operation not to have too many shrink spots, as these may result in drawing the metal out beyond the originally stretched area, causing buckling and warping. Should this occur, the area will have to be stretched again using a hammer and dolly.

Some auto body men dispense with the use of a dolly block—merely heating, hammering, and quenching, but best results are obtained by hammering the metal smooth while hot.

If the stretch in the panel is long and narrow, it is best to shrink a small spot at each end first and then shrink the area in the center. It sometimes happens that a sharp, badly stretched groove will show itself on a panel which cannot be bulged to the outside. In such cases it is better to heat and bring the stretched metal up with a dolly block, then smooth—and quench.

The shrinking technique may be continued in various spots on the panel until its proper contour is restored.

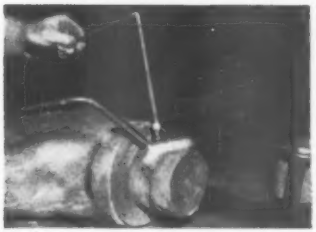

Fig. 1 Bronze-surfacing can reclaim worn parts that otherwise would have to be scrapped

Fig. 2 Good cleaning and proper preheat will produce good tinning and sound welds

Fig. 3 The worn area has been built up slightly higher than the surface so it can be machined

Hints for Bronze-Surfacing

by W. O. Whitehead

BRONZE-SURFACING is a fast way to repair worn parts. Parts that would have to be scrapped, can be reclaimed by bronze-surfacing and put back to work in a short time. When wear-resisting bronze welding rod is applied to the worn surface and the surface is finished to its original size, the part is as good as new. The same equipment—a welding blowpipe, bronze welding rod, and Brazo flux—that is used for braze-welding, can be used for bronze-surfacing. Here is a typical bronze-surfacing job that reclaims cast iron agitator blades when the shanks become badly worn and grooved and puts them back to work. Here's how the job is done.

First, the worn surface is cleaned with a file and steel wool to get rid of all old rust, scale or grease. The blowpipe flame is adjusted so that it has a slight excess of oxygen, then the worn surface is heated to a very dark red. At the same time an inch or so of the end of a length of Oxweld No. 31T bronze rod is heated in the flame and then dipped into the flux can. Now the end of the welding rod is placed on the heated part and some of the rod melted.

If the metal is clean and heated to the right temperature and the proper flux is used, the molten bronze will flow smoothly onto the metal and provide a good tinning coat. If the part is too hot, the molten bronze will boil and run around like water on a hot stove. If it is too cool, the molten bronze will form balls and won't tin. A dirty surface can also cause poor tinning and a bad weld.

Now, maintaining the original heat, the end of the welding rod coated with flux is placed in the area to be built up. Rod metal is deposited on the part forming a puddle. The flame, rod, and puddle are moved slowly around in the worn area until bronze rod has been deposited to build up the groove to the original surface.

In bronze-surfacing be sure to keep the rod in the puddle when weld metal is added. When flux on the rod is used up, dip it into the flux again. Hold the inner cone of the flame about $^1/_4$ to $^1/_2$ in. above the puddle.

Enough weld metal probably can be deposited at one time. But if the surface isn't high enough, heat the weld metal until a puddle is formed again and deposit another layer. Always be sure to remelt the first layer as you weld or the new metal and metal from the first deposit won't fuse properly.

When the weld is completed, let the part cool, clean off the flux, and machine the part down to the proper size to go back on the job.

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Inclined Fixture Spots Diesel A-Frame for Safe and Easy Welding

by C. D. Lentz

FABRICATING the A-frame of the Baldwin-Westinghouse locomotive Diesel from $^{3}/_{8}$ to 4-in. steel plate is mostly a routine electrical welding operation. Analyzing the project from the standpoint of maintenance cost, hazards of scaffolding and convenience of the welders led to the design and construction of an inclined fixture that can be rotated and locked at any angle required.

The stand, built of welded steel plate, forms a bedplate to which the workpiece can be clamped. To provide easy access for the welder, the fixture is mounted on pedestals, one of which stands at a higher elevation than the other so the frame will be tilted at an angle of 45 degrees. The fixture is counterbalanced to facilitate rotation by hand, and a notched disk and dog hold it securely in any position. A large handwheel made of pipe sections welded together provides the necessary leverage for turning the fixture and workpiece.

Mounted on each side is a sliding stairway constructed of sheet steel and built at the same angle as the fixture so the welders easily can get at any part or section. The stairways are mounted on supports made from sections of pipe welded together and fitted with hand rails. Each stairway can be moved sideways to clear the engine frame when it lays on its side.

C. D. Lentz is Manager, Manufacturing Engineering Dept., Baldwin-Lima-Hamilton Corp.

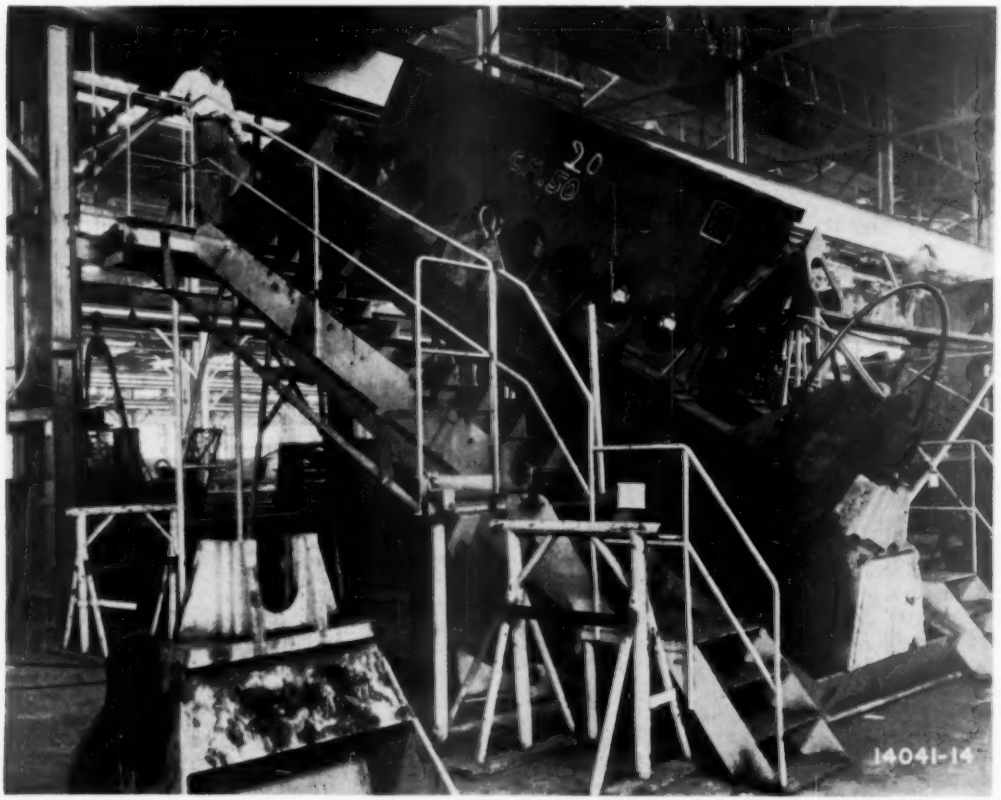

Fig. 1 To provide easy access for the welder, the fixture is mounted on pedestals, one of which stands at a higher elevation than the other so the frame will be tilted at an angle of 45 degrees

Repair Overcomes Replacement Problems

A REPAIR technique that will help maintain production in the face of the shortage of replacement parts uses submerged melt welding to repair cracks and holes in cast steel slag pots for open-hearth furnaces. These vital parts have been repaired seven to eight times faster by submerged arc welding than with other methods, and the finished welds are as serviceable and strong as the original, undamaged slag pot.

Portable size Unionmelt apparatus makes these repairs easy and convenient for the operator. Since this method does not produce heavy fumes, operators do not need air respirators and the absence of glare also adds to welding ease.

While the present part shortage has increased the importance of repair, comparisons of replacement costs with costs of repair suggests that submerged-arc repair of damaged slag pots will outlive the present emergency. A new slag pot costs $1100 while repair expense varies from $20 to $150 depending on the extent of damage.

Fig. 1 Damaged slag pot being repaired by submerged arc welding. Defective area is grooved with gouging nozzle, or cut out and a new section fixed in place by hand arc welding which provides a backing for submerged arc welding

Turntable Speeds Heavy Scrap Cutting

A DESIGN feature of the scrap cutting installation at Allegheny Ludlum Steel Corp., Brackenridge, Pa., is a turntable which gives considerable flexibility to the unit. A machine carriage rides on a track, one section of which can be rotated horizontally—just like a railroad locomotive turntable—to any desired angle. This simple revision of a stationary cutting unit saves one or more moving operations.

With the turntable, it is not necessary to position the scrap sections after each cut in order to reduce them further. Since the direction of cut is always parallel to the alignment of the track that guides the machine carriage, cuts can be made in any direction by simply revolving the table.

Additional flexibility of operation is obtained by providing a swivel between the machine carriage and the horizontal support to which the blowpipe is attached.

Fig. 1 With the turntable rotated 90 degrees, the cutting operator adjusts the height of the blowpipe as a cut progresses

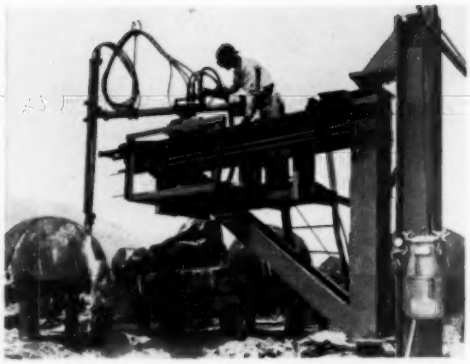

Fig. 2 The operator begins another cut at approximately 90 degrees to the first one

This makes it possible to rotate the blowpipe independently of the carriage or turntable. Slag-encrusted skulls and other large steel and cast iron scrap members are efficiently reduced to charging box size with this setup.

An Oxweld C-60 cutting blowpipe, with powder-cutting attachment, is mounted on the rigid arm attached to the machine carriage. Steel sections up to five feet thick can be severed with this powder-cutting equipment.

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(*Continued from page 414*)

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Broken Casting Repaired Economically by Arc Cutting and Brazing

ARC cutting and brazing served importantly in a repair that saved $1305.36 and 12 days of downtime for a contractor at San Jose, Calif.

An accident had happened to a crawler tractor. A broken capscrew in the grease had caused a series of breaks in the final drive housing. The seriousness of these breaks is evident from Figs. 1–3.

A new housing would have cost $900. It was estimated that 256 man-hours would have been required for disassembly and reassembly with the new part. With labor at $2.29 per hour, this would have meant $1486.24 for the job.

By undertaking the repair by welding with only partial disassembly, total labor on the job involved only 64 man-hours which cost $146.56. Supplies consumed cost $34.32, as itemized below, and brought the total repair cost to $180.88. Repair was completed in 4 days as against 16 days estimated for putting in a new casting if one could be promptly obtained.

Cost Record		
Materials—	18# All-State No. 41 General Purpose Brazing Rod	$21 42
	10# All-State All-Purpose Cutting Electrode	4 90
	1 Tank Acetylene	4 00
	1 Tank Oxygen	4 00
Labor—	64 hours @ $2.29 for partial disassembly and reassembly and for weld preparation and completion	146 56
	Total	$180 88

Estimated cost of new part and attendant labor $1,486 24
Saving $1,305 36
Time: 4 days vs. 16 days

Fig. 1 Partial disassembly of Allis-Chalmers HD-5 Crawler tractor showing breaks in final drive housing caused by a broken cap screw in grease

Fig. 2 Broken pieces were pressed back in place with jacks and tack welded. Casting was then veed along the broken line with a cutting electrode

Courtesy of All-State Welding Alloys Co., Inc.

Fig. 3 One view of the completed welds showing partial distribution of the 18 lb. of brazing alloy used in making the repair

Silver-Brazing Jobs

by K. R. Shepard

SILVER-BRAZING differs from soft soldering in that the brazing solder melts at a higher temperature—usually between 1160 to 1500° F. Another important difference is that silver-brazed joints must fit tightly together. There should be only a few thousandths of an inch between the surfaces to be joined. Good and poor designs for silver-brazing joints are shown in Fig. 1.

You can use silver-brazing for making strong, permanent connections in oil and fuel lines, in hot water and steam lines, and for joining nickel-plated brass tubing where a clean, attractive appearance is needed. Since the brazing alloys are highly resistant to corrosion, use them also for repairing vats, tanks, kettles and other containers used for food.

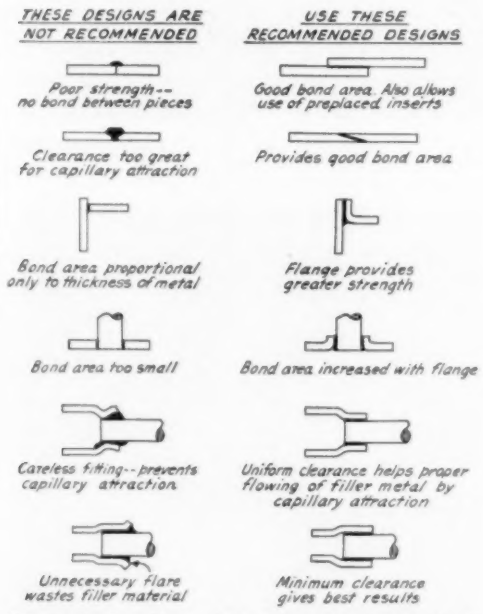

THESE DESIGNS ARE NOT RECOMMENDED
USE THESE RECOMMENDED DESIGNS
Poor strength--no bond between pieces
Good bond area. Also allows use of preplaced inserts
Clearance too great for capillary attraction
Provides good bond area
Bond area proportional only to thickness of metal
Flange provides greater strength
Bond area too small
Bond area increased with flange
Careless fitting--prevents capillary attraction
Uniform clearance helps proper flowing of filler metal by capillary attraction
Unnecessary flare wastes filler material
Minimum clearance gives best results

Fig. 1 Good and poor designs for silver-brazing joints

K. R. Shepard is connected with the Linde Air Products Co., Cincinnati, Ohio.

Table 1—Silver-Brazing Alloys

Grade no.	*Composition*	*Melting point, Degrees Fahrenheit*	*Flowing point, Degrees Fahrenheit*	*Color*
2	Silver, 20% Copper, 45% Zinc, 35%	1430	1500	Yellow
3	Silver, 20% Copper, 45% Zinc, 30% Cadmium, 5%	1430	1500	Yellow
4	Silver, 45% Copper, 30% Zinc, 25%	1250	1370	Nearly White
5	Silver, 50% Copper, 34% Zinc, 16%	1280	1425	Nearly White
6	Silver, 65% Copper, 20% Zinc, 15%	1280	1325	White

GRADES 2 and 3—Use on copper, brass, bronze, and other copper-base alloys; also on steel and for joining dissimilar metals.
GRADES 4 and 5—These are the popular grades for all-around use.
GRADE 6—Excellent for Monel: used by silversmiths because of the white color and low melting point.

Table 1 lists standard grades of silver solders best suited for repair work. Most jobbers have these solders in different sizes of wire and gages of sheet that you can cut into strips.

JOINING COPPER TUBING

The joint shown in Fig. 2(*a*) is a common one for silver-brazing. Usually, joints like this one are made in copper tubing. Here's how to do it:

First clean the parts thoroughly. Use only steel wool to do this. Course emery cloth or a file will scratch the areas to be joined and prevent a good joint. Next

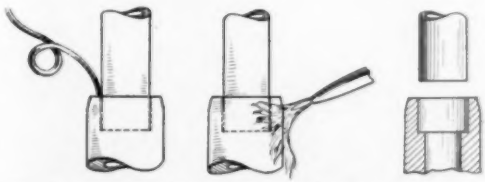


Fig. 2 A common joint in copper tubing made by silver-brazing. Parts are cleaned, fluxed and fitted together. After heating, solder is applied to the joint where it melts and is drawn into the joint by capillary attraction

paint the parts with a good flux. Your jobber can supply you with a good silver-brazing flux. Apply it as directed by the manufacturer.

Homemade flux can be made by dissolving common borax in hot water. Keep adding borax until no more will disolve; then pour the solution through a strainer to remove any undissolved borax. A little boric acid added to this solution will make it spread better.

After you clean and flux the parts, fit them tightly together. There should be not more than a few thousandths of an inch between the surfaces. They are now ready for heating.

Use a small welding head, and adjust the blowpipe for a soft, brush-like flame. Get a neutral flame with a sharply defined inner cone and a bluish outer flame.

Now begin heating the joint, as shown in Fig. 2(*b*). Keep the inner cone a few inches away from the metal surface, and move the blowpipe around the joint until the parts are heated to the right temperature. You can judge this temperature by touching the solder to the joint, with the flame turned away from the solder. If the joint is hot enough, it will melt the solder. With a little practice, you will develop the knack of heating to the right temperature.

When you have heated to the correct temperature, move the flame away and apply the solder, see Fig. 2(*c*). A grade 2 or 3 solder will make a good job. The solder will be drawn into the joint. When a line of solder shows completely around the joint, you have applied enough solder. If necessary, reheat the joint for an instant, and apply more solder until the joint is completely filled.

HINTS FOR REPAIRING FOOD CONTAINERS

Leaky food containers and dairy equipment, made of stainless steel or nickel alloys such as Monel, are best repaired by silver-brazing. Usually repairs have to be made along the seams. Here's how to repair a seam in a Monel food container.

First clean the area around the leaky seam, then paint it with good silver-brazing flux.

Now adjust the blowpipe for the soft brush-like flame again, and heat along the seam. Apply solder to the area after it's heated to the right temperature. Use a grade 6 solder this time. Judge the temperature the way you did before. Continue until you fill the seam with solder.

SIX POINTS FOR GOOD SILVER-BRAZING

The methods for silver-brazing are almost the same as for soft soldering. The important difference is that silver-brazed joints must fit tightly together. Here are six important points for good silver-brazing.

1. A good design for the joint. (Fig. 1 will help you choose a good design).
2. Thoroughly cleaned metal surfaces.
3. Proper flux and a good silver-brazing alloy of the right kind for the job.
4. A clean, hot source of heat.
5. Careful heating of the joint to correct temperature.
6. Applying solder carefully so that it is drawn well into the joint.

Nickel-Bronze Gear Repaired by Inert-Gas-Shielded Arc Welding

WHEN final machining revealed several deep defects in a costly nickel-bronze gear, the gear was easily made sound with inert-gas-shielded arc welding, according to the Linde Air Products Co.

First, the defects in the gear were chipped out to sound metal. Then an operator quickly built up the chipped-out areas using a Heliarc torch and a rod that was cast especially for this job.

Repairs in this tricky-to-weld metal presented no problem for inert-gas-shielded arc welding. For this particular job, alternating current was used, about 300 amp. The $^1/_4$-in. welding rod was cast from nickel-bronze material exactly the same as that used for the gear. Almost all commercial metals can be welded with this process. Argon gas shields the weld from the effects of the air.

Courtesy, The Linde Air Products Co.

Fig. 1 Defects in this nickel-bronze gear quickly repaired by means of inert-gas-shielded arc welding

the AMERICAN WELDING SOCIETY

activities • related events

National Fall Meeting Plans

The National Papers Committee has completed arrangements for one of the most interesting programs for the Fall Meeting of the SOCIETY that could be devised. Some innovation in arrangements have been necessary. For example, Monday morning will be devoted to Award of Prizes and the Adams Lecture. This will be followed in the afternoon by three simultaneous technical sessions devoted to Fabricating Procedures, Resistance Welding, and Hard Facing and Flame Hardening. In order to provide an opportunity for greater amount of discussion, these technical sessions on Monday afternoon and throughout the week will be limited to three papers in so far as possible. Tuesday morning will be given over to three simultaneous technical sessions dealing with Resistance Welding, Weldability and Structural Welding. In the afternoon the sessions will cover additional papers on Weldability, Resistance Welding and Nonferrous Welding. As in other years, there will be an Educational Lecture Series. This will start Tuesday afternoon. The Lecture Series, this year, will be given by Walter H. Wooding on "Inert-Gas-Metal-Arc Welding Processes." On Wednesday morning there will be two simultaneous technical sessions on Nonferrous Welding and Weldability. In lieu of the third session a plant visit is scheduled. Wednesday afternoon will include sessions on Weldability, Brazing and Bronze Welding, Maintenance and Gas Cutting, as well as a continuation of the Lecture Series. On Wednesday evening there will be the usual University Dinner and University Conference. The technical sessions Thursday morning will include Inert Arc Welding, Brazing and Marine Construction. There will be no formal technical sessions on Thursday afternoon although there will be a short business meeting and a Board of Directors meeting. Friday morning will include simultaneous sessions on Pipe Welding, Inert Arc Welding and Marine Construction.

The President's Reception will be held on Monday evening and the Annual Dinner of the SOCIETY will be held on Thursday evening. An unusually attractive program has been arranged for the ladies. Details will be announced later.

The papers for the technical sessions have been selected with unusual care by the National Papers Committee to provide a balanced program of practical applications, research work and general information.

Joint Meeting AIEE-AWS-IEESD

A successful three-day welding conference was recently concluded in Detroit, Mich., on Apr. 16–18. A great many of the aspects of present-day modern welding techniques and problems characterized the program for this Third Annual Welding Conference which was held at the Rackham Memorial Bldg. The conference was under joint sponsorship of three technical Societies, AIEE, the Detroit Section of the AMERICAN WELDING SOCIETY and the Industrial Electrical Engineers Society of Detroit. The papers included the newest developments in arc and resistance welding, apparatus, research and demonstrations of new machines and techniques. The demonstrations were held on Thursday and Friday evenings from 5:30 to 10:00 P.M. Exhibits included the latest electronic controls for all types of electric resistance and arc welders and demonstrations of several types of welders using these controls. A registration fee of three dollars was charged. In a later issue THE WELDING JOURNAL will include a technical story based upon abstracts of these papers as prepared by Assistant Editor B. E. Rossi. It is hoped that a few of these papers of greatest interest to welding engineers will be reproduced in THE WELDING JOURNAL.

A number of prominent members of the SOCIETY played an important part in the affairs of this conference. Among these were included President C. H. Jennings, J. F. Randall, F. Brandt, Robert McMaster, Myron Zucker, J. Heuschkel, A. Johnson, R. E. Young, D. VanSciver, J. F. Deffenbough, C. R. Molenaar, I. W. Johnson, J. R. Fullerton, R. W. Tuthill, E. Steinert, L. C. Poole, C. E. Pflug, R. J. Krieger, F. B. Jones, W. B. Hills, A. U. Welch and Dr. A. DiGuilio.

National Secretary J. G. Magrath and Technical Secretary S. A. Greenberg attended the conference.

Bound Volume 1951

Bound Volumes of THE WELDING JOURNAL for the year 1951 are available in black imitation leather covers, together with a comprehensive subject and authors index. Price $15, including postage.

This volume, comprising a total of 1156 pages in the JOURNAL and an additional 624 pages in the *Welding Research Supplement*, represents a veritable encyclopedia of information in the welding field. Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

RWMA Prize Paper Contest Closes July 31, 1952

The Resistance Welder Manufacturers Association has called attention to the fact that entries in their Prize Paper Contest must be mailed to arrive not later than July 31, 1952.

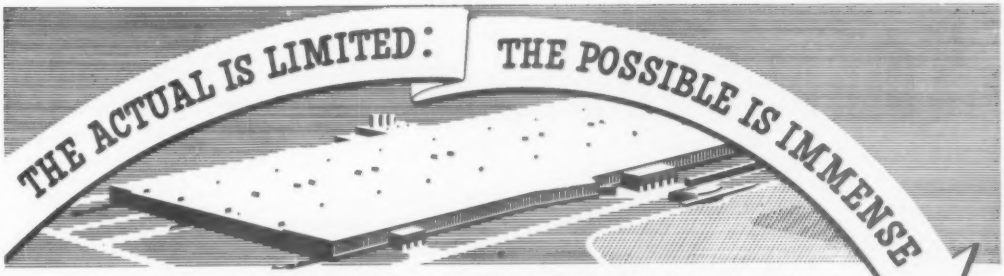
The Contest provides an opportunity to those in Industry or engaged in research laboratory work to compete for a first prize of $750, a second prize of $500, and a third prize of $250.

Papers emanating from a university source (the author of which is either an instructor, graduate student, or research fellow) are eligible for a $300 prize and a second prize of $200 in this classification.

Undergraduate students may submit papers for a $250 award.

The Contest is open to anyone without restriction in the above categories located in the United States, its possessions, and Canada.

For complete details regarding the subject matter of the papers and other Contest Rules write direct to the Resistance Welder Manufacturers Association, 1900 Arch Street, Philadelphia 3, Pa.



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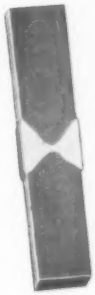

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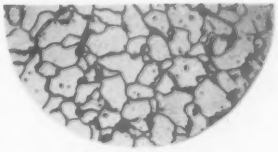

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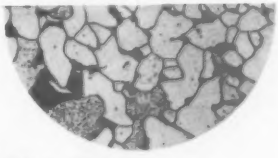

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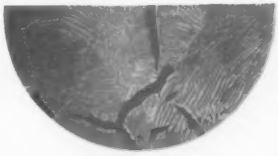

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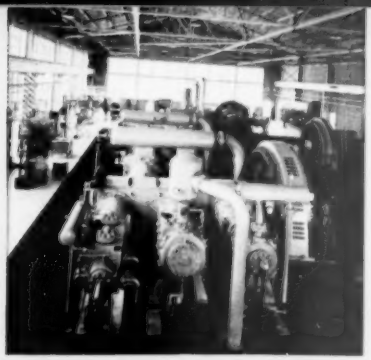

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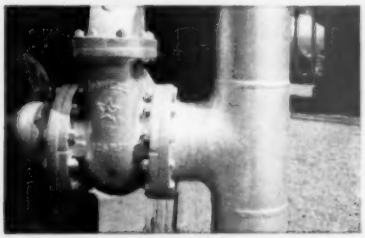

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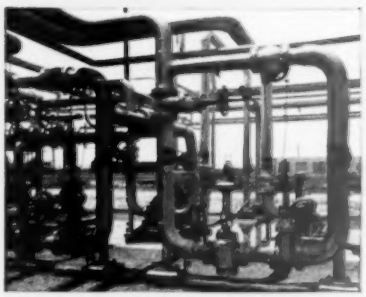

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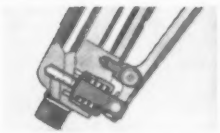

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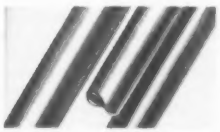

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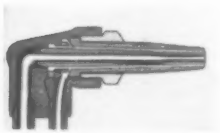

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NEW LITERATURE

Electronics

Proceedings of the National Electronics Conference, 1951, Vol. 7, National Electronics Conference, 852 E. 83rd St., Chicago 19, Ill. 736 pp., charts, diagrams, tables, 9¼ by 6¼ in., cloth, $5.00. This book contains the papers—or digests thereof—presented at the 1951 conference. The 79 papers cover electronic research, development and application in audio systems, components, computers, high-frequency measurement, information theory, magnetic amplifiers, medical and industrial applications, micro-wave and propagation, servo theory, signal detection, television and tubes.

Volumes 2, 4, 5 and 6 may also be obtained for $5.00 per copy.

Reynolds Publishes Literature and Movie Index

Reynolds Metals Co. has just published a new index listing technical literature and motion pictures available to people in the metalworking industry.

Technical literature is listed under five different headings covering Design, Fabrication, Application, Products and General Information—all having to do with how to use aluminum most effectively.

In addition, 7 motion pictures especially prepared for the metalworking industry are listed. These are all on 16 mm., most of them in sound and full color.

The "Literature & Movie Index" will be sent to anyone upon request without charge, by addressing Reynolds Metals Co., Desk "A," 2500 S. Third St., Louisville, Ky.

Report on the Elevated-Temperature Properties of Stainless Steels

This 120-page 1952 Report, prepared by Ward F. Simmons and Howard C. Cross of Battelle Memorial Institute and issued under the auspices of the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals, is essentially a graphical summary of elevated-temperature data for the commercially produced stainless steels. Included are summary curves for tensile strength, 0.2% offset yield strength, per cent elongation, per cent reduction of area, stresses for rupture in 100, 1000, 10,000 and 100,000 hr. and stress for creep rates 0.0001 and 0.00001% per hour (1% in 10,000 and 100,000 hr.).

An Appendix contains the primary data from which the summary curves were drawn. The data sheets in the Appendix give the chemical composition, processing data and other pertinent information about the steels included in this survey.

The following compositions are covered with charts and tables: 18Cr – 8Ni, 18Cr – 8NiTi, 18Cr – 8NiCb, 18Cr – 8Ni-Mo, 18Cr – 8NiMoCb, 25Cr – 12Ni, 25Cr – 20Ni, 25Cr – 20NiSi and 15Cr – 35Ni.

This collection of data resulted from the close cooperation of many leading organizations concerned with the production of stainless alloys, their fabrication into valves, flanges, fittings, piping, etc., and the users. It should be of widespread interest—especially to those establishing stress values and code requirements; the designer of equipment, particularly where elevated temperatures are involved; the metallurgist supervising production of steels or the construction and products therefrom; and the technical people concerned with operating problems.

In order that the graphs and data would show up clearly and in appropriate size for ease of reading, the publication is issued in page size 8½ by 11 in. There are 120 pages and the book is bound in heavy paper cover.

Copies of this "Report on the Elevated-Temperature Properties of Stainless Steels (STP No. 124)" can be procured from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $4.00 each.

The Welding of Nonferrous Metals

The Welding of Non-Ferrous Metals, by E. G. West, Technical Director, The Aluminium Development Assn. Knowledge on the welding of steel is comparatively easy to acquire, for the subject is well documented and much practical experience has been gained during the past few years. Reliable information on the welding of many nonferrous metals, however, has been less easy to obtain, and the purpose of this book is to place on record basic information on the application of the various welding processes to the nonferrous metals.

A list of the Chapters in this book follows: I, "Weldability"; II, "Properties Important in Welding"; III, "Summary of Fusion Welding Process"; IV, "Resistance Welding Processes"; V, "Pressure Welding"; VI, "The Welding of Aluminium and Its Alloys"; VII, "The Welding of Magnesium Alloys"; VIII, "The Welding of Copper and Its Alloys"; IX, "The Welding of Nickel and Its Alloys"; X, "The Welding of Lead and Its Alloys"; XI, "The Welding of Zinc and Its Alloys"; XII, "The Welding of Low Melting Point Metals"; XIII, "The Welding of High Melting Point Metals"; and XIV, "The Welding of Precious Metals."

The book is published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. Including References and Indices the book consists of 553 pages and the price is $8.50.

Encyclopaedia of Oxy-Acetylene Welding

Encyclopaedia of Oxy-Acetylene Welding, by L. J. Tibbenham, M. I. Mech. Eng. This encyclopaedia is a practical work of reference set out in dictionary form to give complete and concise information on all matters connected with oxyacetylene welding. The work contains valuable tables of data required for welding operations, and will be of exceptional value to students, experienced welders and executives who seek knowledge and fundamental facts relating to the subject. The book contains 73 pages with hard cover. The Suffolk Iron Foundry (1920) Ltd., Sifbronze Works, Stowmarket, England, can supply copies post free for two dollars.

All-Welded Steel Deck Girder Highway Bridge

The latest of a series of Studies in Structural Welding has just been published by The Lincoln Electric Co. This 32-page bulletin is entitled *A Modern Steel Deck Girder Highway Bridge* and was written by Ned L. Ashton. The subject of this study, as indicated by the title, is a detailed description of the design and construction of an all-welded steel deck girder highway bridge recently completed across the Iowa River in Iowa City, Iowa. Copies may be obtained by writing to The Lincoln Electric Co., Cleveland, Ohio.

Modern Arc Welding

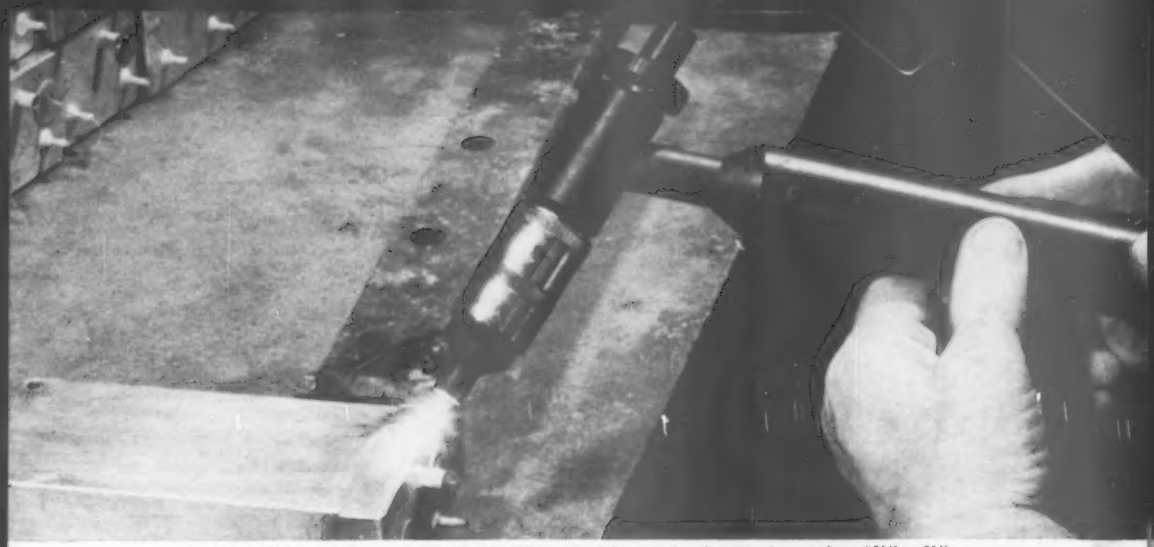
In a new 544-page book, *Modern Arc Welding*, The Hobart Trade School, Troy, Ohio, has made available a comprehensive and practical textbook on the procedure and practice of arc welding. It is of outstanding value not only to the student, but also for the practicing engineer, welding operator and designer.

Clearly written, the 28 chapters are divided in five parts: Part 1 discusses the development of electric arc welding, describes applications, available metals and alloys, joints and welds, electrodes, equipment and other basic procedures. Part 2 constitutes a complete self-study course, incorporating review summaries, practical exercises and "quiz" questions. Part 3 describes in detail the principles and practical operations of carbon arc welding. Part 4 covers other welding processes such as inert-gas-shielded arc welding, submerged arc welding and electric stud welding. Part 5 reproduces the welding terms and their definitions of the AMERICAN WELDING SOCIETY.

The book is illustrated with over 600 photographs of operations, diagrams and charts. The cost of this publication is $3.00.

Mallory Catalog

P. R. Mallory & Co., Inc., Indianapolis, announces the completion of a Product Index, now available to provide specific



You can weld in very close quarters with this 200-amp torch by reducing the extension cap from 3¼" to ¾".

G-E Inert-Arc Torches and Tungsten Reduce Costs, Improve Weld Quality

VERSATILE 200-AMP INERT-ARC TORCH FEATURES EASY, ECONOMICAL OPERATION

Efficient use of gas and ease of operation assure you high-quality welds at lowest cost with the 200-amp G-E Inert-Arc torch.

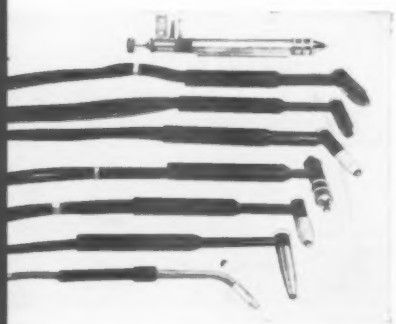
Whatever your application—stainless, aluminum, fernico, Inconel* or any of the hard-to-weld metals—you'll find this light-weight, easy-to-use torch is cooler operating, lasts longer, and assures maximum tungsten life.

The length of tungsten can be adjusted in a matter of seconds by means of the fingertip control knob. Furthermore, you can reduce stub-end loss to only 1⅛ inches.

When damage to the nozzle occurs, the new nozzle design permits refinishing many times without affecting the orifice size.

Available in a continuous rating of 200 amps, this torch comes equipped with 20-foot cables, enabling you to cover over 1000 square feet of floor area. For cost savings and increased production on your toughest Inert-Arc jobs, try the G-E 200-amp torch!

* Reg. trademark, International Nickel Co.



You can weld better and faster with one of the eight types of G-E Inert-Arc torches rated 15-800 amps, air- or water-cooled.

G-E TUNGSTEN IS 99.9% PURE, GIVES STABLE ARC, MAXIMUM LIFE

For neat-appearing welds of highest quality, try G-E tungsten on your next Inert-Arc welding job.

Because G-E tungsten is 99.9% pure and has an extremely high melting point, you get a stable arc, clean, uncontaminated welds and maximum tungsten life. G-E tungsten is available in diameters from .040 to ½ inch, and in lengths from 3 to 24 inches.

HI-THORIA GIVES 10 TIMES NORMAL LIFE, WON'T "BALL UP"

Cut welding costs and improve weld quality on your straight-polarity DC Inert-Arc welding by using Hi-Thoria tungsten. Hi-Thoria won't "ball up" on the end. Hi-Thoria resists contamination, thus reducing operator idle time. Hi-Thoria also provides a very stable arc over a wide current range, and actually lasts more than ten times as long as ordinary tungsten!

Hi-Thoria tungsten (right) resists contamination and balling up usually experienced with ordinary tungsten on DC.

See your nearest G-E Welding Distributor for a complete line of water- and air-cooled Inert-Arc torches, plain and Hi-Thoria tungsten. He also carries welders, electrodes and accessories to meet all your welding needs. You can find his name by looking for General Electric under "Welding Equipment" in the yellow pages of your telephone directory.

GENERAL ELECTRIC

712-13

HI-CONDUCTIVITY
LO-CONDUCTIVITY
New WELDING IMPROVEMENT ASSURES
GREATER CONTROL OVER WELD POWER
WITH
Robotron "CUSHIONED POWER" WELDING TIMERS
THE PROBLEM: To help manufacturers meet more and more exacting specifications issued by government and civilian buyers in the welding of Aluminum, Stainless and Nickel-Alloy Steels, Coated or Plated Metals, or any combination of Dissimilar Metals regardless of conductivity.
To design new, compact electronic controls that can be added to your old or new welding equipment with ease.
To increase welding production at lower cost.
Robotron's ANSWER: A new concept of Vernier Control, the Robotron "Cushioned-Power" Welding Timer pre-heats and prepares the welding material, welds and tempers according to specific needs, assuring welds of minimum surface indentation, maximum ductility and consistant uniformity.
● It welds all combinations of Hard-to-Weld, Plated or Dissimilar Metals.
● Reduces Weld Power KVA (heat) demand and usual required Electrode Pressures.
● Reduces Metal Spewing, Cracking and Surface Indentation.
● Reduces Electrode Pickup and Cleaning Time.
● Cushions impact on Welding Lines — Adds life to Electrodes.
● Can be Added to your present Welding Equipment.
● Can be used in Single-Phase Welding.
● Reduces overall Welding Costs.
Factory time-tested and proven like all other Robotron Electronic Control Equipment, this new "Cushioned-Power" Welding Timer features Compactness, Maximum Accessibility, Easy Installation, Easy Maintenance and Finger-Tip Modulated Power Control. Investigate how Robotron "Cushioned-Power" Welding Timers can increase YOUR welding production — No Obligation, of course.
MODEL W630—H3C4
NEMA 7B Sequence — 1A Synchronous Timer with "Cushioned-Power" Control and 600 Ampere Ignitron Contactor.
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information in condensed form concerning Mallory electrochemical, electromechanical, electronic and metallurgical products.

The catalog is not highly technical in nature but is designed to acquaint engineer and layman alike with basic data on available products. It includes brief descriptions of the specifications, features and applications of the complete line of Mallory batteries, capacitors, contacts, rectifiers, resistors, switches, vibrators, metals and ceramics, tuners and resistance welding supplies.

Copies of the Product Index can be obtained by writing P. R. Mallory & Co., Inc., 3029 E. Washington St., Indianapolis 6, Ind.

Tool Steel Electrodes

The Alloy Rods Co. of York, Pa., announces the availability of their recently released Bulletin A-R 52-1 which covers the company's "Tool-Arc" Tool Steel electrodes for welding tools and dies. This Bulletin is not intended merely as a catalog or sales piece, but rather as a technical and "how to do it" piece which gives valuable welding information. For copy of Alloy Rods Bulletin A-R 52-1 write to E. R. Walsh III, General Sales Manager, Alloy Rods Co., York, Pa.

Arc Welders

An up-to-date folder on their electric drive arc welders has recently been released by the Hobart Brothers Co. of Troy, Ohio. A copy of it may be obtained by writing directly to this company.

Brochure on Pressure Regulators

The National Welding Equipment Co. of San Francisco, Calif. announces the availability of an illustrated 44-page brochure on pressure reducing regulators. This booklet is designed to give the prospective purchaser a clear understanding of how regulators work and upon what basis of performance or specifications he should buy. For your copy, write to National Welding Equipment Co., 218 Fremont St., San Francisco 5, Calif.

Employment Service Bulletin

Services Available

A-628. Welding Engineer. 20 years' experience in welding, engineering and research and development. Principal experience in plate fabrication, carbon steels and the alloy metals, in the shop or field. No experience with the electric resistance type processes. Seeking permanent location, preferably south, including South America.

NEW PRODUCTS

Arc-Welding Helmet

Jackson Products, Warren, Mich., announces a radically new type of welding helmet. The shell is molded in one piece, under high compression, of laminated fabric, phenolic impregnated. It is claimed that this thermosetting material, by being more resistant to high heat, and much less moisture absorbent, will hold its shape better than the commonly used vulcanized fiber. It is said to be strong, smooth and easy to clean.

Cover glass is replaced from the outside with no other parts to come loose, filter lens from the inside; no tools are needed. All helmets are checked for light leakage under strong light.

Headgear is of smooth plastic, readily adjusted (and held firmly) to any head size. A cork-padded sweatband is held by snap buttons. The shell is easily raised and lowered on manually adjustable friction pivots, yet held firmly in any desired position.

Welding Oven for Drying Electrodes

Despatch Oven Co., Minneapolis 14, Minn., announces a new oven specifically for welding applications.

Model WRD-1 Welding Rod Drying Oven assures high welding efficiency by completely eliminating moisture absorption in low-hydrogen and other coated electrodes. Gravity convected heat and economical storage are provided right at the point of use. The welder can maintain an even flow of work without interruption. The Despatch system cuts down rework costs, under-bead cracking and rough welds.

The oven is square and compact in design to occupy minimum space. Gloved hands can easily open the oversize door latch. Ten separate compartments hold 250 lb. of electrodes. These compartments are removable for handling larger units. The reinforced mesh shelving permits efficient circulation of heat and controls moisture, and the rugged construction and baked wrinkle finish withstand rough use.

Semiportable Oxygen Generator

The Joy Mfg. Co. of Pittsburgh, Pa., has announced the development of a semiportable oxygen generator that supposedly will enable industrial users to produce their own high purity oxygen at reported savings up to 50%.

The generator is described as being a compact unit requiring a space of 600 cu. ft. (8 by 7½ by 10 ft.). Simplicity is its keynote and it has a minimum of moving parts. The machine has no dependence on chemicals and nothing is consumed except air and power. Models are contemplated by Joy in the size range from 0.5 to 12 tons daily capacity of oxygen of 99.5% purity.

Despite the small size of the unit, it is reported that it can produce high purity oxygen at an operating cost of five to ten cents per 100 cu. ft., depending on how much of the time it runs. This is equivalent to $12 to $24 per ton.

Heart of the Joy oxygen generator is a series of automatic reversing heat exchangers which eliminate the expense of chemical purification of the air and contribute to high efficiency.

For additional information, write to Joy Mfg. Co., Henry W. Oliver Bldg., Pittsburgh 22, Pa.

Simplified Electronic Welder Control

Square D Co. announces a new simplified design of its electronic nonsynchronous resistance welder control. This design simplification provides easier installation, less maintenance, smaller size and greater mounting versatility.

Drastically simplified NEMA 3B weld and sequence timing circuit requires only 4 tubes plus valve relay and firing relay. Extreme consistency and timing accuracy are maintained, according to the manufacturer, and all tube circuits are "fail safe." Firing of power tubes is synchronized to minimize transients and case stress on the welding transformer.

Interchangeable NEMA 3B and 5B timer panels are quickly detached from the door. Plug connectors to the power pack in the cabinet permit easy replacement.

Much smaller in size, this new controller (15 x 15 x 37 in.) requires little more space than formerly needed for the ignitron contactor alone.

Enclosure design permits wall (as illustrated) or side-of-machine mounting with the same controller and without the additional trouble of relocating the adjuster dial assembly. Installation is easier because of generous wiring space below the contactor, and a vertical wiring channel extending the full height of the cabinet. All components are arranged for maximum accessibility.

For further information, write for Bulletin 8992 on *Electronic Non-Synchronous Welder Control* and its application to spot and projection welders. Address Square D Co., 4041 N. Richards St., Milwaukee 12, Wis.

Aluminum Sheet "Cleanliness" Tester

One troublesome factor in the welding of aluminum sheet is the so-called "cleanliness" of the sheets as presented to the welding head. The surface electrical resistance, in microhms, is a measure of the effectiveness of the oxide removal or cleaning process employed.

The new Model 151-S Microhm Meter, according to the J. W. Dice Co., can readily measure the total surface resistance of two sheets, or coupons, when placed between two dummy electrodes. Also, it is claimed that it can accurately measure a resistance as low as one millionth of an ohm (0.000001 ohm), and that the readings are practically instantaneous. The instrument scale is 0–75 microhms and is linear. If it is necessary to read higher resistance values than 75 microhms, a

this new WELDING DESIGN MANUAL

FOR THE ASKING

To assist you in your re-tooling problems . . . or to help you analyze your present welding methods so that you may enjoy maximum speed, efficiency, and economy in many of YOUR production problems . . .

Giant new 4th Edition contains 62 new photographs, 132 new drawings, 72 pages of helpful data covering basic and advanced welding techniques and designs used in fabricating and assembly. Profusely illustrated with application drawings; weld diagrams; tables of melting temperatures, strengths, corrosion factors; charts; alloy recommendations; etc. Convenient digest size.

This just-off-the-press book is "must" reading for anyone engaged in defense production and design, and will certainly be time profitably spent for any production man.

SEE . . .The unbelievable savings in metal-joining which can now be yours through the use of "Low Temperature Welding Alloys"® discovered a few years ago and now used in over 78,000 industrial plants throughout America for more efficient metal-working production as well as for salvaging irreplaceable tool and machine parts.

Over 100 different, new, EUTECTIC Low Temperature WELDING ALLOYS® and EUTECTOR® Fluxes are job-engineered for use on ALL metals – cast iron, alloy steels, aluminum, copper and nickel alloys, die castings, overlays, etc., and may be applied with ALL heating methods – torch, arc, furnace, induction heating, etc.

SEND FOR YOUR COPY TODAY!

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This new manual of yours sounds like a very helpful book. Send me a FREE copy with the understanding that there will be no cost or obligation now or later.

Signed_____
Firm_____
Address_____ Zone_____
City_____ State_____

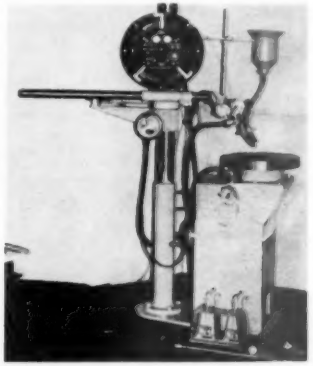
selector switch cuts in various multipliers which permit taking measurements up to 750,000 microhms.

The instrument is intended to be a shop, or service-type, instrument designed for maximum ruggedness and reliability. It is contained in a heavy oak case with waterproof finish. Total weight, including internal battery power supply, is 22 lb. For additional information write to the J. W. Dice Co., Englewood, N. J.

Special Fixture for Submerged-Arc Welding

A special fixture for submerged-arc welding has been built by the Goetz Corp., Milwaukee, Wis., to position, hold and rotate tractor parts. Circular welds are efficiently made by submerged-arc welding with this setup. The table is a circular one on which the formed parts are concentrically positioned. It can be tilted to a 45-degree angle.

An unusual design feature of the fixture is an air chuck for holding the parts to be welded. This reduces loading and unloading time to a minimum. Another time- and effort-saving feature is the use of an air cylinder for moving the Unionmelt welding head in and out of welding position. With the head away from the welding area there is no obstruction to clearing and reloading the table, thus minimizing the possibility of accidental personal injury or damage to apparatus.



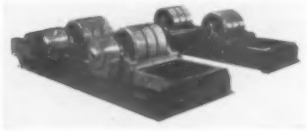
This Fixture has been specially designed for submerged-arc welding of tractor parts. (Courtesy of the Linde Air Products Co.)

Before a weld is started, the weld metal and the tip of the rod are completely covered with granulated welding composition. During welding, this composition conducts the welding current and protects the weld zone from the atmosphere. There is no visible arc—no sparks, spatter or smoke—and no weld metal contamination. With submerged-arc welding, high quality welds can be made at high speeds and low cost.

Heavy-Duty Turning Rolls

A new addition to the line of heavy-duty turning rolls designed and built by Reed Engineering Co. of Carthage, Mo., has been announced by this company.

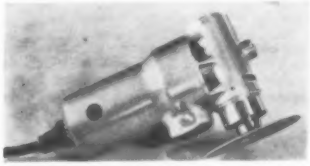
Known as the Model M-1500, the roll has a capacity of 75 tons with one power unit and two idler units, and handles vessels up to 14 ft. in diameter.



The new design features a compact, three-in-one motor-variable speed transmission-gear reducer set with a range from 5 to 40 in. per minute, totally enclosed, direct-drive worm-gear reducers and antifriction bearings. The 5-h.p. motor is protected with a reversing magnetic starter, and antijog reversing relays. The rubber-tired wheels are 22 in. in diameter and have a 21-in. face.

Disk Grinder

The Diskette, a new precision high-speed disk grinder, 9 in. long, weighing only 4½ lb., and designed for one-hand operation, has been introduced by the Balmar Corp. of Baltimore for use in welding shops and foundries. Priced to sell at $69.50, the tool is designed to withstand continuous duty, and polishes, grinds, sharpens and shapes all types of metals to a high degree of accuracy.



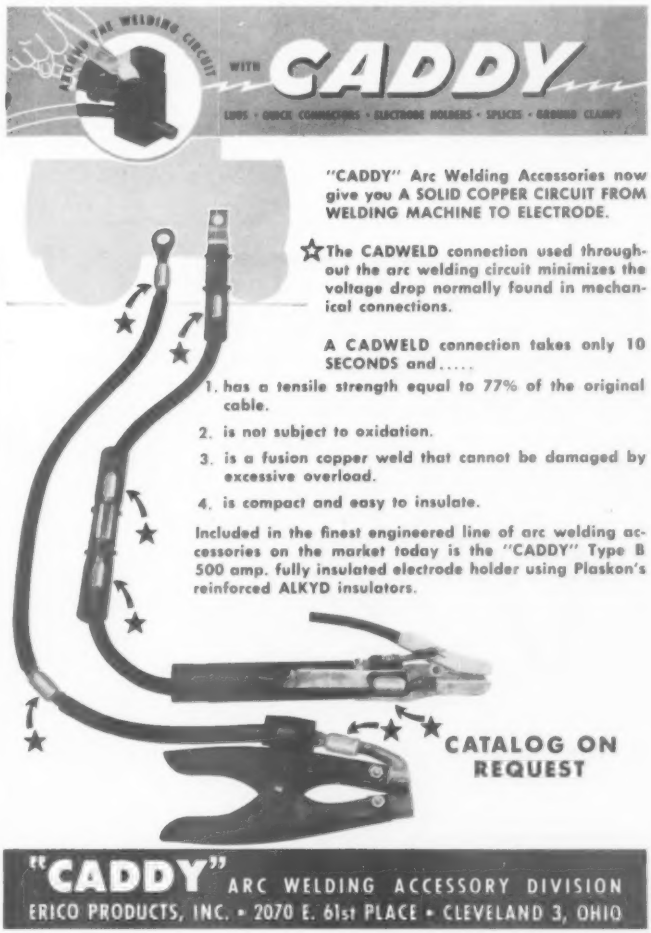
Its speed of approximately 8000 rpm. enables the new industrial tool to provide smooth finishes and highly polished surfaces. Because of its small size and light weight, the Diskette can be easily operated in close quarters. Its outside diameter is 2¾ in., and its weight is approximately half the weight of comparable hand tools. Welding shop and foundry applications of the Diskette include the cleaning of castings, knocking off sprues, gates and risers, dressing off welded spots, removing chill nails and grinding them smooth.

Met-L-Chek Inspection Process

The Met-L-Chek Co., of 121 N. Prairie Ave., Hawthorne, Calif., announces the development of the Met-L-Chek penetrant dye inspection process.

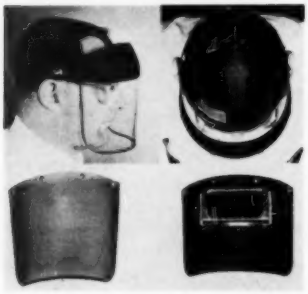
The Met-L-Chek process detects cracks, pores and cold shuts in all types of metal parts which are often microscopic in size and therefore cannot be seen by the inspector.

According to the manufacturer, Met-L-Chek works as follows: (1) Parts are swabbed with highly penetrant red dye solution. Dye penetrates any cracks or pores within three minutes. (2) Surface dye is washed away with water. Surface tension of water prevents it from penetrating microscopic cracks—therefore only the dye in the cracks remains. (3) Parts are swabbed with developer solution (white). This dries quickly leaving a white coating which sucks the dye out of the cracks the same as a blotter sucks up ink. The dye spreads out through blotting action leaving a vivid red stain many times wider than the flaw—and therefore visible to the naked eye.


COMPLETE THE WELDING CIRCUIT
WITH
CADDY
LUGS • QUICK CONNECTORS • ELECTRODE HOLDERS • SPLICES • GROUND CLAMPS
"CADDY" Arc Welding Accessories now give you A SOLID COPPER CIRCUIT FROM WELDING MACHINE TO ELECTRODE.
☆The CADWELD connection used throughout the arc welding circuit minimizes the voltage drop normally found in mechanical connections.
A CADWELD connection takes only 10 SECONDS and.....
1. has a tensile strength equal to 77% of the original cable.
2. is not subject to oxidation.
3. is a fusion copper weld that cannot be damaged by excessive overload.
4. is compact and easy to insulate.
Included in the finest engineered line of arc welding accessories on the market today is the "CADDY" Type B 500 amp. fully insulated electrode holder using Plaskon's reinforced ALKYD insulators.
CATALOG ON REQUEST
"CADDY" ARC WELDING ACCESSORY DIVISION
ERICO PRODUCTS, INC. • 2070 E. 61st PLACE • CLEVELAND 3, OHIO

Three-in-One Face Shield

A face shield with sufficient clearance to be worn over glasses and industrial goggles has been designed and manufactured by The Boyer-Campbell Co., Safety Division, 6540 St. Antoine St., Detroit 2, Mich., and will be identified as Model No. 301. The shield is glove-buttoned to a form fitting head gear which is readily adjusted to any shape or head size, eliminating all high-spot contact and providing complete comfort for the wearer. Its greater clearance also affords better ventilation. Three types of shields are interchangeable on one head gear: (1) Plastic shield for general utility; (2) fiber front with glass holder for gas welding and (3) screen window for scaling, heat, cyaniding, etc.



Stud Welder

A new Portable Stud Welder has just been added to the Graham Line which requires only an electrical connection for operation. Wherever there is electric power in 110, 220 or 440 a. c., the new "3000" welder can be used. Wattage pull is less than a home flat iron.

Operation is simple—the operator loads a stud in the collet and applies a small amount of pressure to a spring-loaded stud holder which fires the stud.

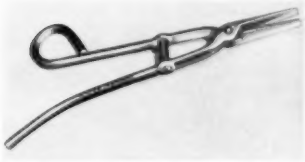
This unit has a wide range of applications due to its flexibility and ability to apply studs in otherwise inaccessible places.

Simple construction of the stud holder provides a wide variety of stud sizes and shapes, including hooks, and headed studs in a wide variety of sizes up to $\frac{1}{2}$ in. diameter.

New Safety Tongs

A new, huskier, more durable pair of safety tongs has been developed by Atlas Welding Accessories Co., 707 Lewiston St., Ferndale 20, Mich., for metal working and other industries.

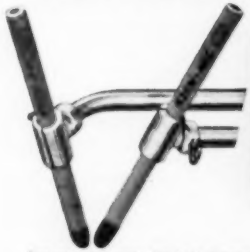
The new tool is constructed of drop-forged steel with long, broad nose members to provide a firm grip. Nose members are also thin at the tip, making them ideal for use in removing blanks from presses, selecting and removing single sheets from a pile, handling hot parts, lifting parts from solutions, etc.



By heating, the nose may be spread or reshaped as desired for handling special shapes. The tool is also available with a guard over the spring for index finger guiding.

BECKER

KEEN-ARC CARBONS



FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc.
Write for catalog.

BECKER BROTHERS CARBON CO.
3450 South 52nd Ave. Cicero 50, Illinois

Now...
ARC-DRIVE CONTROL
for D-C Rectifier Welder

...Instantaneous response to arc-load changes
...Instantaneous recovery
...Reduced arc blow
...Completely adjustable by operator

Westinghouse RA Welders with new positive arc-drive control now prevent shorting when used on "drag" welding applications. In addition, they allow complete penetration on root passes of vertical and overhead welds. Arc-drive control is obtained by adjusting the ratio of short-circuit current to welding current without changing open-circuit voltage. Actual amount of arc-drive current can be varied by the operator.

For information on this improved RA Welder or other Westinghouse Welding Equipment, write Westinghouse Electric Corporation, Dept. DC-85, Welding Division, Buffalo, New York. J-21607-A-1

YOU CAN BE SURE... IF IT'S
Westinghouse
WELDING EQUIPMENT

"Lawn mowers, trucks, or carnival rides—— I fix 'em all with ANACONDA-997 Low Fuming Bronze Welding Rods."

— says CLAUDE CAMPBELL
Warren County Welding Company
Lebanon, Ohio

Claude Campbell, owner of Warren County Welding Company, shows how he braze-welds a two-speed truck differential housing.

Campbell pauses for a breather in front of his shop that services four counties in southern Ohio.

Campbell demonstrates the use of AnacondA Welding Rods in making repairs on a power lawn mower.

"Lawn mowers and trucks are routine jobs. But it's not often a shop gets a carnival ride to fix. Last summer, at the county fair, an old Century Motor Ride burned out its motor brush—couldn't get a new one. The breakdown was costing them money. Busy as I was, I made one from a piece of spring, brazed with an ANACONDA Welding Rod. Got the ride going that night."

Claude Campbell takes wor' like this in stride. To build up worn surfaces or join cast iron, el, or galvanized steel, he uses ANACONDA-997 (Low Fuming Bronze Rods for speed and penetration—for low melting point and free-flowing qualities. He can file, grind, or machine bronze welds easily. Since less preheating is required, he finds little danger of warping or cracking. Economy of ANACONDA Rods is important, too.

Mr. Campbell praised his jobber, O. K. I. Welding Supply in Cincinnati. Their salesman—a practical welder himself—contributes many good ideas. The ANACONDA distributor near you can help you make more money and find the right bronze rod for the job. Consult him—and for more information, write for Booklet B-13 to The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

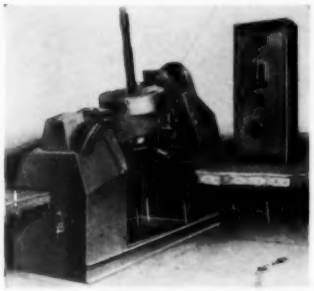
BRAZE OR WELD WITH CONFIDENCE

ANACONDA®

WELDING RODS

New Positioner for Welding Jet Engine Turbine Wheels

In welding the turbine-bucket wheel to the forged shaft of a turbo-jet engine, an extremely high quality of weld is required, and the welding process must follow strict specifications. The bead is laid down on both sides of the wheel in an exactly defined sequence, and the welded area must be kept at a temperature of 600° F. during the welding operation.



The new J-47 welding positioner consists of a cradle which is power-rotated through 180 degrees so that welding can be performed on both sides of the assembly. The assembly is carried on a variable-speed rotating spindle and is enclosed by power-operated insulated doors equipped with ports for welding. Thus the operators have clear access to the work and yet are protected from heat and splatter.

The assembly is maintained at 600° F. by means of gas burners controlled by motor-operated gas valves and with manually operated secondary air valves. An interlocking system of electric controls maintains ignition, firing and gas pressure.

Welding speed can be varied exactly as required by means of a special heavy-duty, variable-speed gear reducer designed to withstand the blows of the chipping hammer without injury to the gear train.

While the J-47 positioner is designed for hand welding, it is easily adaptable to automatic welding of any approved type. Designed and manufactured by the Syracuse Special Machine Co., 4010 Court St., East Syracuse, N. Y.

Turco Formulates Speedy Chek-Spek Inspection Method

Development of a new, high-speed dye penetrant inspection process, formulated to serve those industries in which production-line inspection is desired was announced recently by President S. G. Thornbury, Turco Products, Inc.

The new, nonflammable product, called Turco Chek-Spek, is a partner of Turco Dy/Chek, the completely flexible dye penetrant inspection process. Use of nontoxic Turco Chek-Spek, permits accurate evaluation of an almost unlimited number of inspections per hour.

Nonflammable Turco Chek-Spek, when used in conjunction with a vapor degreaser, requires only two materials—Chek-Spek Penetrant (flash point 140° F.) and Chek-Spek Developer (flash point 180° F.). Following precleaning by vapor degreaser, the red Chek-Spek Penetrant is applied to those parts being inspected. After being allowed to dwell sufficiently long for it to enter even the smallest defect that extends to the surface, the surface dye is removed by suspending the parts for a few seconds in the vapor zone of a vapor degreaser. Following dye removal the white Chek-Spek Developer is sprayed onto the parts being inspected. Strong Developer capillary attraction pulls out the dye which has remained trapped in existing flaws. As the white Developer dries, the red dye bleeds into it, clearly locating and defining the extent of existing flaws.

Complete information regarding this nontoxic, nonflammable production line inspection process may be obtained from Turco Products, Inc., 832 E. 62nd St., Los Angeles 1, Calif.

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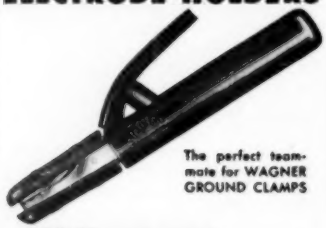

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abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,586,471—Compressible Brazed Connector—Irving Frederick Matthysse, New York, N. Y., assignor to Burndy Engineering Co., Inc., a corporation of New York.

This patent is on an electrical connection including a connector with a tongue and a ferrule portion and having therein the end of a stranded wire conductor. The ferrule has a seam running the length thereof sealed against moisture by a braze. The material of the braze is crimped into the conductor to key to the conductor and strengthen the connection.

2,586,516—Inert-Gas-Arc Welding Electrode—James D. Cobine, Schenectady, N. Y., assignor to General Electric Co., a corporation of New York.

Cobine's welding electrode is made of tungsten capable of starting an arc instantly and maintaining a stable arc at temperatures below the incandescent temperature of tungsten. The electrode includes a material providing zirconium oxide at the arcing terminal to form a stable cathode spot thereat.

2,587,056—Process for Detecting Faults in the Welds While Being Made—Archie K. McElroy, Springfield, and Louis C. McNutt, Scotch Plains, N. J.

This novel process consists in placing a source of radiation on one side of the weld and also in placing a hollow jig on the opposite side of the metal with a radiographic film on the outer surface of the jig. A cooling fluid is passed through the jig so that pictures of the weld may be taken even though it is at a temperature of around 1600° F.

2,587,195—Method of Electric Arc Welding—Willem Moerman, Eindhoven, Netherlands, assignor to Hartford National Bank and Trust Co., Hartford, as Trustee.

In this welding method a touch welding rod is provided and it has a core with a coating thereon. This coating melts more rapidly than the core during welding to form a crater at the arc end. An edge of the coating is maintained in abutment with the metallic workpiece when initiating a welding arc. The edge of the coating is maintained in abutment with the workpiece as the rod is moved along the path of the weld. A slot is provided in the piece to be welded and the welding rod is positioned facing the welding path so that the arc is continuously confined in the crater formed in the electrode and light from the arc escapes to illuminate the workpiece in the region where the weld is yet to be made.

2,587,251—Method of Electric Arc Welding—Paul Christiaan van der Willigen, Eindhoven, Netherlands, assignor to Hartford National Bank and Trust Co., Hartford, Conn., as Trustee.

A new welding method is disclosed in this patent and it includes placing a nongas evolving semiconductive slagging solid of a predetermined shape and size in a position to establish the contact between spaced workpieces. An electrical current is passed through the workpieces and slagging solid to start an arc and after the arc has burned for a short time, the workpieces are moved into contact with each other and thereafter the current is interrupted.

2,587,296—Process of Obtaining Torch Flame—Albert Jean Ducamp, Chaville, France.

Ducamp's process comprises introducing into the torch operating gases formed from an alkyl glyceroborate and methylglyceroborate dissolved in methyl alcohol.

2,587,461—Device for the Adjustment of the Starting Position of the Blow-Pipe in Oxygen-Cutting Machines—Gilbert Gatimel, Paris, France, assignor to L'Air Liquide, Societe Anonyme pour l'Etude et l'Exploitation des Procedes Georges Claude, a company.

A specialized device for making the adjustment indicated is covered by this patent.

2,587,821—Valved Construction for Torch Handles and Method of Making the Same—Alfred F. Chouinard and Mitchell A. Tylutki, Chicago, Ill., assignors to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

As indicated by the title, a special valved construction and method of making it is disclosed in this patent.

2,587,840—Welded Article and Method of Making the Same—Frederick A. Gruetjen, Milwaukee, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

An electric flask welded tank including a cylindrical body is disclosed in the patent. A closure is provided for the body and the patent relates to the use of a compressible insulating gasket ring disposed in a portion of the closure comprising a reverse bend in a flange of the closure. The gasket is compressed between flared sections of the closure and the body as the closure is wedged into end engagement with the body. The gasket substantially prevents inward upset of the edges in welding.

2,587,849—Horizontal Fire Tube Welded Boiler—Homer L. Hosking, Scarsdale, N. Y., assignor to Republic Boiler Corp., New York, N. Y.

A special boiler of the type indicated is disclosed in this patent.

2,588,062—Electrode Arrangement for Fence Welding Machines—Rudolph C. Vorderstrasse, Sterling, Ill., assignor to Northwestern Steel and Wire Co., Sterling, Ill., a corporation of Illinois.

A relatively large complicated machine is disclosed in this patent for making a welded fence. The apparatus is adapted to provide a plurality of sets of opposed electrodes so that a pair of welds can be simultaneously accomplished by a series flow of welding current through opposed sets of electrodes.

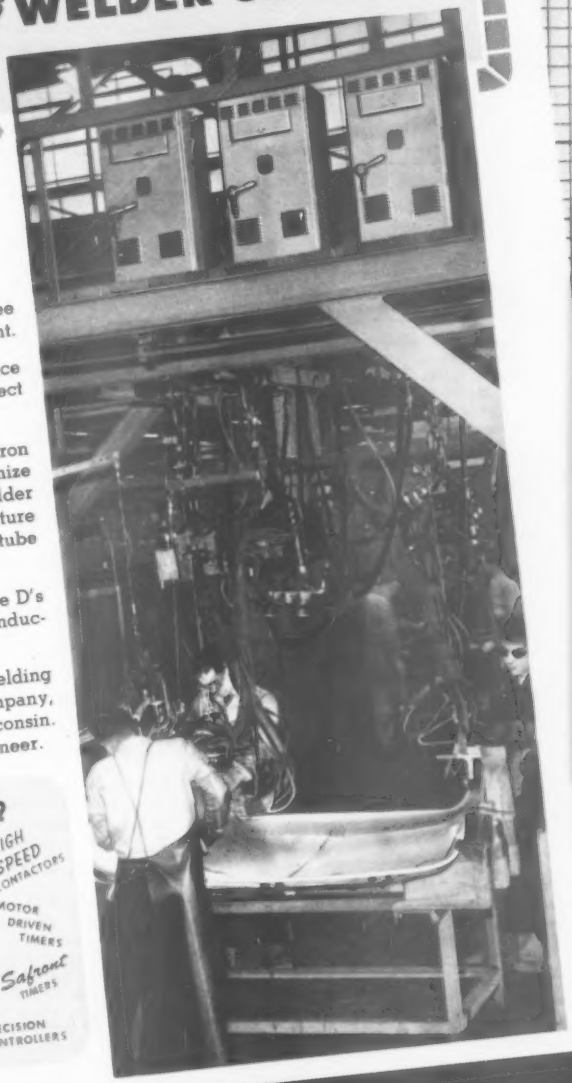
2,588,553—Welder's Eyeshield—Arthur McWethy, Grand Rapids, Mich.

This patented structure includes a circular head band, and a pair of goggles mounted on arms pivotally carried by the head band. A chin strap controls the goggle support arm.

2,588,700—Welded Joint—Otis R. Carpenter, Barberton, Ohio, assignor to The Babcock & Wilcox Co., Rockleigh, N. J., a corporation of New Jersey.

The joint disclosed is for use involving corrosive fluid at steel embrittlement temperatures. Duplex metal welds unite the components welded together. Each weld has a special root deposit of steel and an overlying steel deposit of a specified composition and which will harden when cooled quickly from above 1375° F. and which has good ductility when quenched from 1375° F.

LOWER PRODUCTION COST WITH SQUARE D *Electronic* WELDER CONTROL



New Cleveland Automotive Plant Uses Square D Control on Gun Welders

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LESS INSTALLATION TIME was needed since the contactor, sequence-weld timer and disconnect are combined in one enclosure.

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MORE CONSISTENT WELDS because Square D's lead-trail circuit feature insures full-cycle conduction and prevents transformer saturation.

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SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Low-Alloy Steels

Baltimore, Md.—W. H. Wooding, AWS, Philadelphia Naval Shipyard, Philadelphia, Pa., was the guest speaker at the March 21st dinner meeting of the *Maryland* Section held at the Engineers' Club in Baltimore. Mr. Wooding is Superintendent of the Metals Section of the Industrial Test Laboratory. His talk on the "Welding of Air Hardening Low-Alloy Steels" was illustrated with slides and described the problems arising from the welding of this type material and the research conducted in the determination of the applicable welding procedures. He stated that the development of the lime type austenitic electrodes and low hydrogen electrodes has aided in the welding of these steels. He described the Navy patch test which was used to determine the relative weldability of the electrodes used and showed X-ray photographs and photomicrographs of various test plates. The apparatus employed in the study of preheats and interpass temperatures was shown. In an effort to reduce the preheat and interpass temperatures a cladding technique was tried and this resulted in the ability to lower the temperatures and obtain crack-free joints. Mr. Wooding also described in detail the investigation conducted to determine the isothermal and time-temperature transformation characteristics. He described the test assembly used for the determination of cooling rates of single-pass welds and showed cooling curves for various preheat temperatures. Cooling rate curves were given for various welding currents, rates of arc progression and preheat temperatures, respectively, as the variables. The relationship of cooling rates to time-temperature transformation characteristics was shown. Mr. Wooding's talk was well given and in addition to giving the details of the tests, furnished the audience with an insight of the research being carried on by the Navy in the development of improved welding procedures.

Coffee speaker was S. S. Alden of the Baltimore Branch of the F.B.I. Mr. Alden gave an excellent talk on "Your F.B.I. and How It Functions."

Maintenance Welding

Bridgeport, Conn.—Charles C. Keyser, AWS, Welding Engineer, Bethlehem Steel Co., Steelton, Pa., gave an extemporaneous talk on "Maintenance Welding" at the February 21st dinner meeting of the *Bridgeport* Section, held at Rapp's Restaurant, Shelton, Conn. Mr. Keyser's non-technical, shop-level illustrated talk was of general interest to engineers, shop management and arc-gas welders. The talk covered application of the different types of welding to steel mill maintenance, with special emphasis on automatic and semi-automatic submerged arc welding applied to maintenance work. Around 60 slides were used to illustrate the talk.

The coffee speaker was Master Sgt. Clifford A. Holmes, U.S.M.C., who showed an excellent film on the extensive "Training of the U. S. Marines."

Spring Stag Party

Bridgeport, Conn.—The *Bridgeport* Section Executive Committee held a dinner meeting at Rapp's Restaurant on Monday, March 3, 1952, at seven o'clock, to discuss plans for the forthcoming meetings to be held in March, April and May.

At this meeting it was decided to forego the usual spring party with the members and their wives and in its place to have a stag affair with a caterer at a private club with refreshments and entertainment. As this is the first time this has been done in the section it is hoped by the committee that it will be a big success and that it will be well attended by the members and their friends.

Resistance Welding Applications

Buffalo, N. Y.—F. L. Brandt, AWS, Sales Manager, Thompson Electric Welder Co., Lynn, Mass., was a techical speaker at the March 27th dinner meeting of the *Niagara Frontier* Section held at the Sheraton Hotel, this city. Mr. Brandt covered the subject "Resistance Welding Applications and Equipment" extemporaneously. New methods and processes as well as new applications were covered in Mr. Brandt's address.

Forty-six members and guests were present at dinner and 169 were in attendance at the technical meeting.

Inert-Arc Welding

Chicago, Ill.—One of the largest turnouts at a meeting of the *Chicago* Section took place on February 15th. Dinner was held at Burke's Grill and Restaurant with an attendance of 77 and the technical session, with an attendance of 208, took place in the People's Gas Light & Coke Co. Auditorium. This large turnout was to hear Harry E. Rockefeller, AWS, Assistant Manager, Development and Process Service, Linde Air Products Co., give a paper on "Inert-Gas-Shielded Arc Consumable Electrode Welding." The well-received talk was illustrated with slides and a color motion picture taken at ultrahigh speeds showing the metal deposits in the arc with variations in current, type of metal and various inert gases and gas mixtures. The animated discussion following Mr. Rockefeller's address had to be stopped in order to enable the speaker to catch his train.

Prior to the technical paper, members and guests enjoyed motion pictures showing the hunting of pheasant and wild geese.

Resistance Welding

Chicago, Ill.—The subject "Resistance Welding" was presented by R. T. Gillette, AWS, Welding Engineer, Precision Welder and Machine Co., at the meeting of the *Chicago* Section held on March 21st in the Auditorium of the People's Gas Light & Coke Co. Dinner at Burke's Grill and Restaurant preceded the meeting with an attendance of 39. Eighty-eight members and guests were present at the meeting to hear Mr. Gillette discuss the history, processes, equipment and various other phases of resistance welding. A film entitled "This Is Resistance Welding" was shown in connection with the paper and was also very well received.

Safety in Oxyacetylene Industry

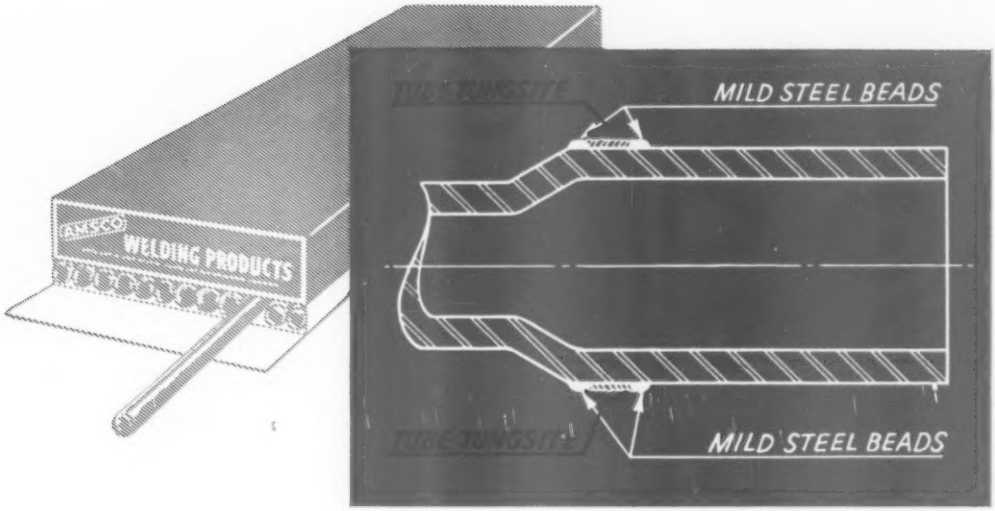
Cleveland, Ohio.—Two motion pictures and a talk on safety were the attractions at the Annual Oxyacetylene Meeting of the *Cleveland* Section held in the Mather Room, Hotel Allerton, on March 12th. This meeting broke the year's attendance record with 140 for dinner and 170 for the meeting.

L. G. Matthews, Associate Engineer, Safety Code Department, Linde Air Products Co., presented the paper on "Safety in Oxyacetylene Industry." He thoroughly discussed code requirements, the safety built into acetylene containers, the tests of containers and safety practices of users.

Mr. Matthews described the production of acetylene and how it behaves. He also told how the gas is stored in cylinders. He explained how the gas becomes unstable at pressures over one atmosphere but how this difficulty is overcome by filling the cylinder with porous material and dissolving the gas in acetone under a pressure of many atmospheres. Mr. Matthews exhibited samples of the filling material which was a composite of cement, asbestos and charcoal and also a cutaway model of a container.

The talk was supplemented by a moving picture showing the various destructive tests of gas-filled containers and their safety devices including the spectacular bonfire test.

James A. Rousmaniere, Assistant to the President of Taylor-Wharton Iron & Steel Co., discussed oxygen cylinders. His talk was illustrated by a very interesting motion picture "3000 Psi," showing in great detail the manufacture, testing and inspection of cylinders.



How to increase output by increasing collar life

An example of how Amscoating with AMSCO Hardfacing Electrodes can save materials, manpower, and money.

When you don't have to stop drilling operations because of collar wear, output is bound to go up. Several West Coast drilling contractors report greatly increased service life after Amscoating with Tube Tungsite. It's for this kind of service involving severe abrasion that AMSCO Tube Tungsite is ideal.

In this application, the mild steel bead dilutes the AMSCO Tube Tungsite deposit at the shoulder for greater toughness and high resistance to impact at the point where it's needed most. The Tube Tungsite provides the high level of abrasion resistance in the center section of the collar.

Welders prefer it, too. The excellent weldability of AMSCO Tube Tungsite using either AC or DC makes it highly preferred by welders for the continuous welding of the collars.

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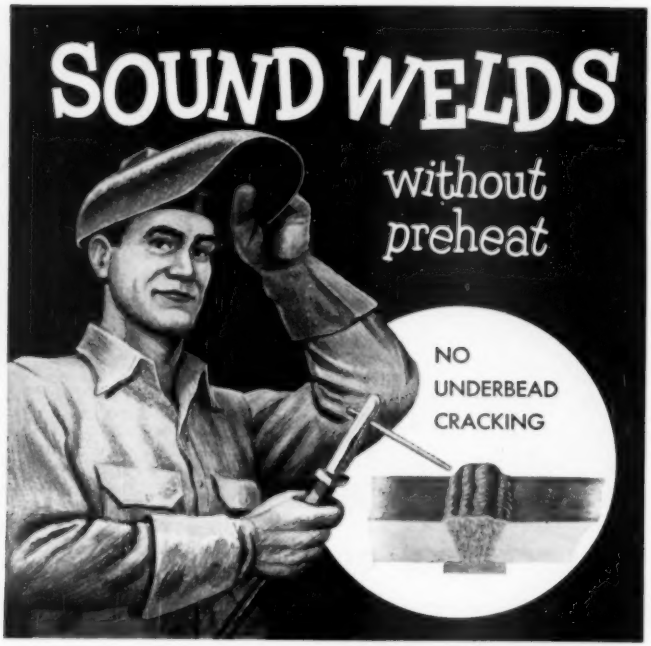

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The first half hour of the technical meeting was devoted to the solving of welding problems by the question-and-answer method. Solutions to questions from the floor were offered by a panel composed of E. B. Pederson, AWS, gas applications; Otto Uher, testing inspection and welder qualifications; Frank Flocke, AWS, fabrication; Ernie Lauter, AWS, resistance; L. K. Stringham, AWS, arc and metallurgy. Lew Gilbert, AWS, performed the functions of moderator.

The meeting was adjourned at 11:00 o'clock after the showing of the film "Oxyacetylene Flame—Master of Metals," produced by the International Acetylene Association. The film showed a number of oxyacetylene welding and cutting applications and also the way in which the torch does its work.

The Cleveland Section is having excellent results in a membership drive. About 40 new members were signed up the first month of a $2^1/_2$-month drive. Incentive is provided by a prize of a $15 hat to the person signing up the most new members by May 1st. Every person signing up new members has one chance for each new member he signs up in a drawing for a second $15 hat (except the winner of the hat for signing up the most members).

The membership campaign awards will be made at the 13th Annual Welding Symposium held at Hotel Allerton on Friday, May 9. The Cleveland Section has not copyrighted this idea, and the plan may be used by other sections in their membership work.

Sigma Welding

Dallas, Tex.—The March meeting of the *Dallas* Section was held on the 19th in the Auditorium of the Mercantile National Bank with an attendance of 52. Dinner at Brockle's Restaurant preceded the meeting.

J. E. Dato, AWS, Service Supervisor, Linde Air Products Co., Kansas City, Mo., presented an excellent semitechnical talk on "Shielded-Inert-Gas-Metal Arc Welding" which was of interest to the engineer as well as the operator. Mr. Dato's talk was illustrated with slides and motion pictures.

Welding Engineering Research

Denver, Colo.—C. B. Voldrich, AWS, Chief Welding Engineer, Battelle Memorial Institute, Columbus, Ohio, presented an excellent technical talk on "Welding Engineering Research at Battelle" at the March 11th dinner meeting of the *Colorado* Section held at the Oxford Hotel, Denver.

A 16-mm. film entitled "An Orchid for Mr. Jordan" was shown through the courtesy of the U. S. Steel Co. The picture had sound effects and was well received.

Speedy Spot Welding

Detroit, Mich.—An invitation to the ladies by the *Detroit* Section to join the members at dinner brought a good response. A total of 70 sat down for dinner

on March 14th prior to the meeting held at the Rackham Memorial Building. A masterful talk on "Good Government" was given by the coffee speaker, T. D. Leadbetter, City Clerk of Detroit.

The technical session was held in the auditorium and was taken over by the Square D Co. of Detroit and Milwaukee. Talks and demonstrations on "Square D 60-Cycle Circus" (Controls for Speedy Spot Welding) were in the capable hands of Frank Roby, Ed Stanbach, Jim Brown and Bud Whitney, all of whom were given a wonderful reception by the 178 members and guests.

The "circus" consists of Square D controls demonstrating a new electronic-magnetic taskmaster which puts large press welders through their paces; also some new nonsynchronous controls; all done electronically.

To top off the evening the entire group were the guests of the Square D Co. for a buffet lunch in the dining room.

Hard Facing

Fort Wayne, Ind.—Howard S. Avery, AWS, Research Metallurgist, American Brake Shoe Co., Mahwah, N. J., was the principal speaker at the regular monthly meeting of the *Anthony Wayne* Section held on March 28th at the Indiana Technical College. In his subject "Hard Facing for Impact and Abrasion" Mr. Avery explained abrasion testing and the relative performance of the many alloys used to resist wear, from the tough manganese steel to the very hard martensitic irons. His talk contained a great deal of advanced hard facing and the savings in cost, whether you were a job operator doing hard facing on farm tools, a plant maintenance or production welder facing the task of prolonging the life of wearing parts, or an executive or designer faced with the problems of saving overhead cost in increasing the life of your product. Mr. Avery said many of the merits of hard facing stem from the special materials used. He also covered the welding techniques and their advantages. He has had a continual study of hard facing and has been identified with the American Brake Co.'s Research Works for many years. His talk was supplemented with slides. Forty-five members and guests attended the meeting and all went home richer in knowledge on hard facing for impact and abrasion.

Plans are now being made for a plant tour of Baldwin-Lima-Hamilton Corp., Lima, Ohio, on May 16th.

Plant Tour

Grand Rapids, Mich.—Eighty-seven members and guests of the *Western Michigan* Section met for dinner at the Elks' Club Cafeteria on March 24th. Following dinner a plant tour through the Transportation Division of the American Seating Co. was made by 95 members and guests. This was a very educational tour through the many departments of the company where flash-spot-arc and gas welding were seen. One interesting department was the brazing of tubular steel with the use of gasflux. After the tour the

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gathering returned to the company cafeteria for "Cokes" and a showing of the AWS film "Applied Welding Engineering" which drew favorable comment and a request to hold the film over for the Annual Spring Symposium held on April 18th. The Educational Department of the American Seating Co. is to be commended for a very enjoyable and highly educational tour.

Sigma Welding

Houston, Tex.—One hundred and nine members and guests were present at the monthly dinner meeting of the *Houston* Section held on March 21st at the University of Houston, Oberholtzer Hall, to hear J. E. Dato, AWS, Southwestern Division Service Manager for the Linde Air Products Co. Mr. Dato, who has been instrumental in the continued development of inert-gas welding, spoke on shielded-inert-gas-metal arc welding—more commonly known as "Sigma Welding." In illustrating his talk Mr. Dato showed movies of the action of the arc stream when various shielding gases and varied welding machine conditions were used. These movies, taken at 1600 frames per second and then slowed to standard projection speeds, gave the audience an insight into the arc action and deposition rates of Sigma Welding. Continuing his talk using illustrated slides to show various applications of this welding process Mr. Dato discussed the high weld quality, the high deposition rates, the cost factors involved and the adaptability of the process to both ferrous and nonferrous metals.

The Section is continuing its program of inviting student guests to its meetings and at this meeting two members of the University of Houston engineering school were present. At the next meeting it was announced that University of Texas students had been invited. Also, as is the custom, 15 new AWS members were introduced to the Chapter. Preceding the meeting a film "Welds Without Walls" was shown through the courtesy of the National Tube Co., a subsidiary of the United States Steel Corp.

Aircomatic Welding

Indianapolis, Ind.—J. W. Cunningham, AWS, Air Reduction Sales Co., Dayton, Ohio, gave an excellent talk on "Aircomatic Welding and Its Applications" at the February 22nd meeting of the *Indiana* Section held at Buckley's Restaurant, Cumberland, Ind. Mr. Cunningham's presentation was accompanied by motion pictures and slides. At the conclusion of his talk Mr. Cunningham opened the meeting to a very interesting question-and-answer session.

Tours

Kansas City, Mo.—The members of the *Kansas City* Section had a choice of two plant tours through the Westinghouse jet engine plant, Aviation Gas Turbine Division, on March 20th. The first tour started at 9 A.M. and the second at 1:30 P.M. A total of 40 members enjoyed the two tours.

Considerable stainless steel welding was observed using the metallic arc, Heliarc and spot-welding processes.

The regular meeting was called to order at 8 P.M. by Chairman Les Powers who introduced the speaker for the evening, G. H. Willecke, AWS, of the Miller Electric Manufacturing Co.

Mr. Willecke gave an excellent talk on the "Design of Rectifier Type D.-C. Arc Welder." He discussed the six types of rectifiers. The advantages and disadvantages of each type were also very thoroughly discussed. Slides were used to illustrate his talk.

Mr. Willecke is a Physicist with the Miller Electric Mfg. Co. He was born in Germany and attended elementary school there, finished prep school in the U. S., entered State Teachers College at Stevens Point and did graduate study at the University of Wisconsin. He has taught physics at Wisconsin high schools and at Lawrence College and has worked as a physicist for the Air Materiel Command at Wright Field. He participated in the 1946 National Geographic Air Force cosmic ray flights to South America. Since 1948 he has been associated with Miller Electric. He is a member of AWS and American Association of Physics Teachers.

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Planning for Welding

Los Angeles, Calif.—A joint dinner meeting of the *Los Angeles* and *Long Beach* Sections was held on March 20th at Scully's Cafe in Los Angeles with an attendance of 300 members and guests of both sections. Charles H. Jennings, National AWS President and Engineering Manager of the Welding Department, Westinghouse Electric Corp. at Buffalo, N. Y., was the guest speaker. Mr. Jennings was visiting Western Sections during the course of a two-weeks' trip to the Coast. The Section members found their President to be an affable gentleman who used just the right amount of seasonable and spicy humor to put his message across.

The newly formed Aircraft Welding Panel of the Los Angeles Section was well represented by the attendance. Francis Stevenson, Chairman, reported on the current activities of the Aircraft Panel. Charles Johnston, AWS, outlined the various phases to be handled by the panel and told about its organic structure. He invited the Long Beach Section to take part in its activities.

Mr. Jennings brought best wishes to the Section from the Home Office, and from the Niagara Frontier Section, of which he is a member. He told about the good, healthy increase in membership within the Society as a whole, and pointed to a goal of 1000 new members, this year. He called attention to the valuable references published by the AMERICAN WELDING SOCIETY in the form of the *Welding Handbook*, codes, pamphlets and practices. Mr. Jennings also pointed out that the SOCIETY is fostering an educational program in various vocational schools and colleges looking toward a degree in Welding Engineering.

The subject of the technical talk given by the President was "Planning for Welding." Mr. Jennings stressed the importance of good product design. He outlined the basic requirements such as well-defined standards for use as a guide, welding symbols to control the type and amount of welding, type of electrodes to develop the strength, and standard physical tests to prove the strength of weldments. Mr. Jennings believes that economical and high-quality welding begins in the design department and depends on proper coordination through the various stages of fabrication.

From the fabrication viewpoint, the speaker pointed out the importance of using the proper electrodes with good welding machines, of qualification tests for the operators, and of physical tests to assure the soundness of the product. Mr. Jennings believes it is better to inspect the work before welding and during welding, rather than after completion. Quality must be built in as the fabrication progresses. He showed some slides depicting the development of welding machines over a relatively short period of time. Some of the earlier machines seemed humorous in the light of present-day advancements.

Resistance Welding Electrodes

Louisville, Ky.—L. W. Sink, Metallurgist for the P. R. Mallory & Co., Indianapolis, Ind., gave an interesting

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PAGE Welding Electrodes AND Rods

story on the work that has been done on resistance welding electrodes at the March 25th dinner meeting of the *Louisville* Section. Mr. Sink discussed his company's development work on the subject over the past years and indicated the type of electrodes that are most suitable for various types of work.

After this interesting discussion a film "Sea Power in the Pacific" was shown.

Party in Milwaukee

Milwaukee, Wis.—The Annual Party of the *Milwaukee* Section will be held on May 24th.

Pressure Vessel

Nashville, Tenn.—"Making of a Pressure Vessel" was the subject of a talk given by R. A. Davis, AWS, of the Chicago Bridge and Iron Co., Birmingham, Ala., at the March 26th dinner meeting of the *Nashville* Section held at Bozeman's Restaurant, this city. A 16-mm. sound, part color film on the same subject was shown through the courtesy of the Chicago Bridge and Iron Co. Both the film and paper were excellent and of interest to all.

Welding Processes

Newark, N. J.—Simon A. Greenberg, Technical Secretary of the AMERICAN WELDING SOCIETY, presented a talk on the role of welding in industry at the February 19th dinner meeting of the *New Jersey* Section held at Essex House, this city. Mr. Greenberg used as a basis for his talk the chart of welding processes which was published in THE WELDING JOURNAL. Also included was a very excellent film and corresponding record on the subject of using welding for fabricating bicycle frames, bridges and hospitals. This strip film and record are always available from the AMERICAN WELDING SOCIETY. Following the strip film, Mr. Greenberg touched on the various welding codes in certain states and communities and how they affected the use of welding as used by State Highway Departments. As a final conclusion several figures were cited showing the tonnages of welding electrodes sold during recent years as well as the dollar value of the welding equipment industry.

An added feature of the meeting was the showing of an excellent 16-mm. sound colorfilm entitled "Pheasants Galore."

Fifty-eight members and guests were present at the meeting.

High-Pressure Steam Pipe

Newark, N. J.—Due to illness, the scheduled speaker, Vincent T. Malcolm, AWS, of the Chapman Valve Mfg. Co., was unable to be present at the March 18th dinner meeting of the *New Jersey* Section held at the Essex House, Newark. Sidney Low, AWS, of the same company, ably presented the talk prepared by Mr. Malcolm on the "Fabrication of High-Pressure–High-Temperature Alloy Steel Piping by Welding."

Mr. Low described the development of alloy high-pressure steam pipe welding. The first field installation of this classification was in the Burlington Station in New Jersey in 1932. He described the new alloys introduced for this service and welding problems encountered in fabricating them. Besides the chrome-molybdenum steels for steam service he also included the high chrome and austenitic steels for corrosion resistance as encountered in the oil refining industry.

Among the welding factors discussed were design of bevels and joints, skill of the operator, preheating and postheating, quality of base metals and electrodes and methods of inspection. Mr. Low also described the metallurgical factors of graphitization in carbon steels and the formation of sigma phase in stainless steels.

The audience was impressed as to the need of rigid procedure and inspection controls for this class of welded fabrication.

An added feature of the meeting was the showing of a 16-mm. black and white film entitled "Antarctic Expedition of 1946."

A social hour with the serving of snacks and refreshments took place after the meeting.

New Section

Olean, N. Y.—Thirty-seven members and guests attended the first meeting of the *Olean-Bradford* Section held on March 24, 1952, at the Option House Hotel at Bradford, Pa. The 38 members of this new Section had, until this time, been affiliated with the Niagara Frontier Section of Buffalo, N. Y.

The present officers are:

Chairman—Herbert Rogers, Clark Bros. Co., Olean, N. Y.

Vice-Chairman—Charles Schuman, Dresser Mfg. Co., Bradford, Pa.

Secretary-Treasurer—Anthony Lorenzini, Daystrom Furniture Co., Olean, N. Y.

Chairman Rogers read the By-Laws and they were accepted as is.

Following the dinner and meeting, the members and guests toured the plant of Bovaird and Seyfang, a subsidiary of Dresser Industries. Bovaird and Seyfang are welders of high-pressure piping and manufacturers of oil field equipment. The tour was thoroughly enjoyed by all.

The May meeting of this newly formed Section will be held on the 12th and in addition to Nomination of Officers for the coming year, the program will include one or two educational films and a sports film.

The June meeting will be held on the 2nd.

The Section Technical Representative is Ralph M. Sutherland of Dresser Mfg. Co., whose home address is Limestone, N. Y. It is the duty of the Technical Representative to receive and hold available for the use of the membership, all technical papers, books, codes, etc., relating to welding, issued by Headquarters. All members of the Section should feel free to contact the Technical Representative on any questions they might have.

Maritime Administration

Pascagoula, Miss.—Earl S. Shulters, AWS, Construction Representative, Office of Ship Construction, Maritime Administration, was the guest speaker at the dinner meeting of the *Pascagoula* Section held on March 5th at the Shipyard Cafe. Sixty-five members and guests enjoyed Mr. Schulters' nontechnical paper on the "Functions of the Maritime Administration." A sound film entitled "Cargoes to Korea" was also shown. M. B. Lanier, President of the Ingalls Shipbuilding Corp., introduced the guests.

Welding Design

Pascagoula, Miss.—"Welding from a Designer's Point of View" was the subject

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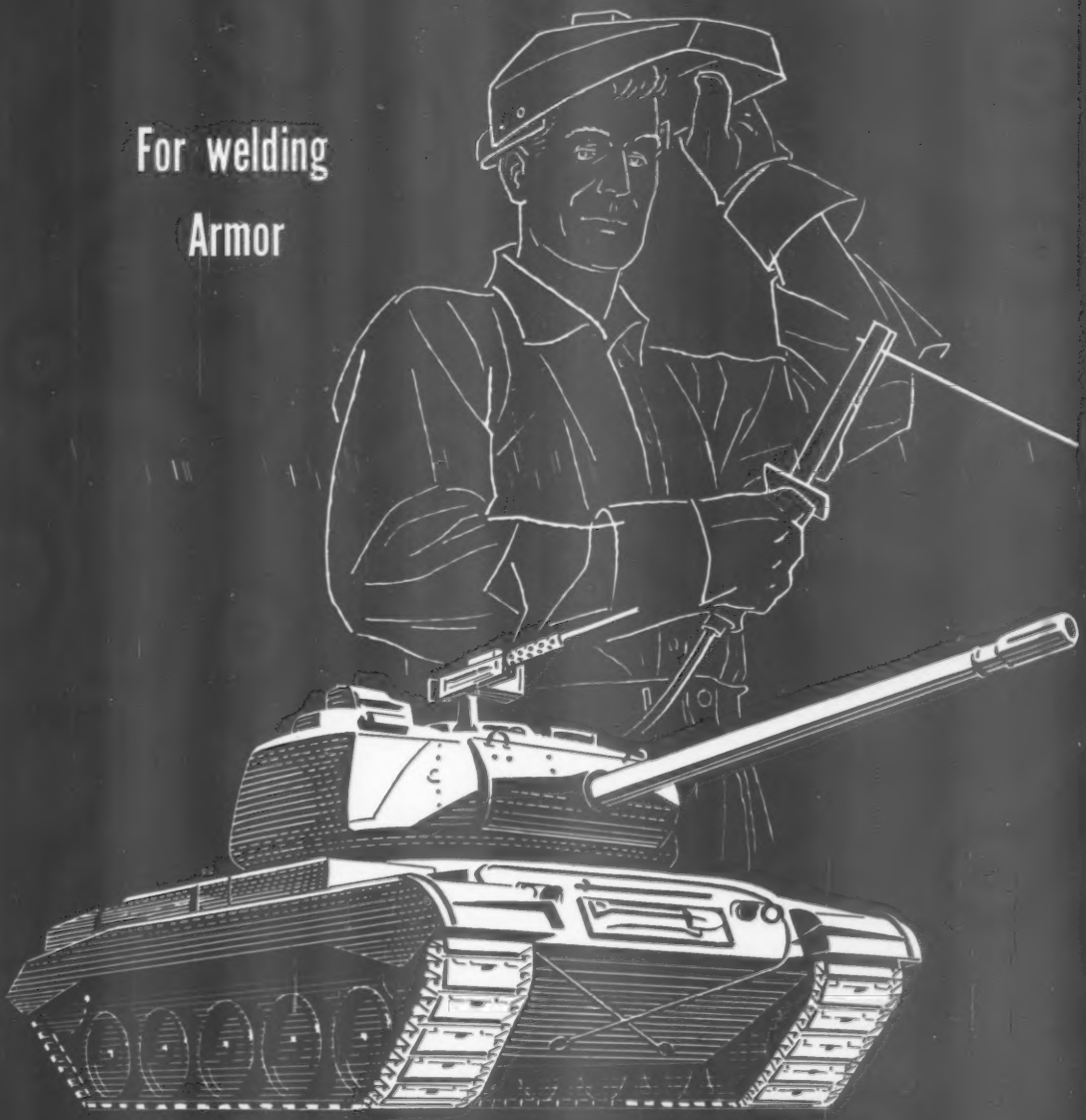

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of an excellent nontechnical paper presented by Stanly M. Bebler at the April 2nd dinner meeting of the *Pascagoula* Section held at the Shipyard Cafe. Mr. Bebler is Chief of Hull Division for Palmer and Baker, Inc., Consulting Engineers, Mobile, Ala.

Alton W. Mansfield, Section Chairman, Welding Operation, Ingalls Shipbuilding Corp., introduced the guests.

Cost Control

Peoria, Ill.—Leslie S. McPhee, AWS, of the Whiting Corp., Harvey, Ill., spoke before the *Peoria* Section on March 19th. The meeting was held at the Sazarac Restaurant where an excellent dinner was served.

Mr. McPhee has charge of all welding operations for the Whiting Corp. He has gained much valuable information and experience in helping manufacture the various products of his company. He has served in various capacities of the Chicago Section of the AMERICAN WELDING SOCIETY, and also on the National Board.

The title of Mr. McPhee's address was "Fabrication Cost Control." The address was accompanied by slides which illustrated good and bad or costly methods of manufacturing various types of equipment. Mr. McPhee was able to show by use of the slides and his talk how to redesign and improve the quality of the product and yet produce it cheaper. He thinks that the industry is becoming more aware of the need of proper design in welding. He illustrated that it is important to make products that are simpler, better and cheaper to produce. He also stated that cooperation between management, engineering and production departments will help in cutting costs by redesigning where practical.

Annual Dinner Dance

Philadelphia, Pa.—The Annual Dinner Dance of the *Philadelphia* Section will be held on May 17th at the Engineers Club. A. M. Garcia is Chairman of this event. C. W. Middlestead is in charge of Ticket Sales.

Welding Metallurgy

Phoenix, Ariz.—The regular monthly dinner meeting of the *Arizona* Section was held on February 20th at the Westward Ho Hotel.

Following the dinner a very informative talk was given by the speaker of the evening, E. R. Babylon of the Kaiser Steel Corp. on the subject "Some Aspects of Metallurgy in Welding." Having had over 25 years' experience in the steel industry covering production, metallurgical processing, quality control and metallurgical sales-service, Mr. Babylon's talk was well received.

A very interesting film entitled "Strength in the West" was then presented by the Kaiser Steel Corp. showing some of their many activities.

The meeting was adjourned at 10 P.M. by William Garland, Vice-Chairman, who presided in the absence of the Chairman, Arthur Tesmer.

Field-Welded Structural Frames

Phoenix, Ariz.—James E. Hastain, Consulting Engineer of Phoenix, spoke on "Field-Welded Structural Frames—A Transitional Change in Design and Construction" at the March 19th dinner meeting of the *Arizona* Section held at the Westward Ho Hotel. Mr. Hastain traced the development of unit stresses of 12,000 psi. to the present 20,000 in welded construction and predicted even higher value as methods of analysis become more exact and full advantage of welded continuity is utilized. He showed how continuity resulted in weight saving in the huge trusses of the new Navy hangar just outside of Phoenix compared to conventional riveted trusses.

Mr. Hastain also gave a very informative talk on welding symbols and their usage. All present agreed the meeting was very successful and the speaker was invited to present a talk again in the not too distant future to give additional information on symbols.

Hard Facing

Portland, Ore.—A joint dinner meeting between the *Portland* Section and the American Society for Metals was held on March 11th in the Italian Room of the Mallory Hotel.

The speaker was Howard S. Avery, AWS, Research Metallurgist with the American Brake Shoe Co. at Mahwah, N. J. Mr. Avery's subject was "Hard Surfacing by Fusion Welding." There was a turnout of 55 people.

Inasmuch as there is a lot of construction equipment in the Northwest which is hard faced, Mr. Avery's remarks were followed with keen interest. He gave some interesting pertinent facts concerning the technique of hard facing and the composition of different types of rods used for different applications.

Welding, Brazing and Soldering Aluminum

Rochester, N. Y.—G. O. Hoglund, AWS, Supervisor of the Welding Section, Process Development Laboratories, Aluminum Company of America, was the guest speaker at the March meeting of the *Rochester, N. Y.*, Section held at the Rochester Turners Club.

Mr. Hoglund pointed out that many aluminum alloys have been made extremely easy to weld with the development of the inert tungsten arc and the consumable electrode gas-shielded arc processes. There are two broad classifications of aluminum alloys—namely, the heat-treatable, and the nonheat-treatable groups. The strength and physical properties of both groups are controlled primarily by the chemical constituents (such as manganese, silicon and magnesium) and the fact that most welding processes used will reduce the tensile strength of the parent metal adjacent to the fusion line except when in the annealed or as-cast condition.

Mr. Hoglund emphasized the importance of controlling aluminum oxides that are ever present on all aluminum surfaces and have to be removed or broken up with the use of a suitable flux. X-ray quality welds can be made if qualified procedures are followed; however, some fine scattered porosity is usually present.

He also covered the field of brazing and soldering and substantiated his talk with the use of many slides. A question-and-answer session followed.

Mr. Hoglund's address was followed by a sound film "This Is Aluminum" that proved of interest and very educational to all.

William T. Bock, in charge of the Eastern District of the F.B.I., presented

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the coffee talk. His talk consisted of a brief history of the F.B.I.'s origin and the progress made to date; how it functions at all times, whether at war or peace; the qualifications and character of its employees, such as—at the present time—the basic requirement is a college graduate with a degree.

A capacity crowd turned out for the meeting and the good old-fashioned corned beef and cabbage dinner served in honor of St. Patrick. A well-rounded evening was enjoyed by all.

Gun Welders

Saginaw, Mich.—"The History of the Development of Multi-Gun Welders, Circuit Design" was the subject of the talk given by Robert H. Blair, AWS, of the Resistance Welder Corp., at the dinner of the *Saginaw Valley* Section held on March 13th at Zehnder's Hotel, Frankenmuth, Mich. Mr. Blair's remarks covered research methods and applications and was illustrated by slides.

A 16-mm. sound color film "Fishing for Fun" was shown through the courtesy of GMC.

Eighty-one members and guests enjoyed a chicken dinner served before the meeting.

Human Relations

Salt Lake City, Utah.—An open meeting for members and their wives of the *Salt Lake City* Section was held on March 20th in the Seagull Room of the Temple Square Hotel. Sixty men and women were present to hear Dr. Royal L. Garff discuss "How Our Family Relations Affect Our Jobs."

Dr. Garff is at present teaching speech at the University of Utah. He is strictly a "Utah man" who received his Master's and Doctor's degrees from Northwestern University. He was in charge of personnel direction and salesmanship training for Montgomery Ward in Chicago. In 1941 he returned to Utah and has been connected with numerous large firms training salesmen and improving employer and employee relations. From 1945 to 1949 he was an instructor for the Carnegie Speech Course. Dr. Garff has an enviable record of achievements as a public speaker and is in constant demand to give his outstanding talks. Both the speaker and the subject were very interesting.

Engineers' Week

Schenectady, N. Y.—The *Northern New York* Section participated in "Engineers' Week" during the week of February 17–23, 1952, in Schenectady. "Engineers' Week" was supported by all Engineering Societies. The AWS Section was represented on the over-all planning committee by Past-Chairman Jack Frandsen.

The program for "Engineers' Week" was as follows:

Sat., Feb. 16—1:45–2:00, WGY, "Headlines in Religion," the Rev. Daniel Y. Brink discussed the religious aspects of our profession.

Sun., Feb. 17—The Schenectady County Council of Churches urged that engineering be honored in the "Sunday church services."

Tues., Feb. 19—1:30–2:00, WRGB-TV, "Rollin' with Stone" featured Engineers in Communications and Civil Defense.

Wed., Feb. 20—2:00–3:00, WSNY, "Notes to You" interviewed "Women in the Engineering Profession."

Wed., Feb. 20—8:00, ASCE Meeting, Union College Old Chapel, "Highways of the World."

Thurs., Feb. 21—1:00–1:30, WRGB-TV, "Prudence Penny" interviewed "Women in the Engineering Profession."

Thurs., Feb. 21—8:00, AIEE-ASME Meeting, Union College Memorial Chapel, "The Future of the Power Industry."

Thurs., Feb. 21—*GE General Office News* carried a two-page pictorial article on "Engineers in GE."

Fri., Feb. 22—Washington's Birthday honored our first engineer; Engineers' Week purposely included this important day.

Inert Arc Welding of Copper

Schenectady, N. Y.—The inert arc welding process provides the answer to welding copper used in the fabrication of pressure vessels so indicated in a talk by John J. Chyle, AWS, Director of Welding Research, A. O. Smith Corp., at a dinner meeting of the *Northern New York* Section, on March 6th at the Cross Roads Inn, Lathams, N. Y.

Mr. Chyle's talk on this subject was amply supplemented with colored slides, charts and illustrations which showed the classification of copper by grades and effect of small quantities of various alloying elements.

The successful application of inert arc welding for joining copper depends on many factors such as: the selection of proper filler metal, proper joint design, correct welding technique and proper treatment of the joint during and after welding. Thorough inspection is recommended as additional assurance of reliable joints.

Liquid Oxygen Demonstration

South Bend, Ind.—*Michiana's* Section men entertained their ladies at the March meeting held on the 20th at Nabicht Bros. Restaurant. After a wonderful dinner, which included corn-on-the-cob, Robert Thuerbach, Evansville, Ind., District Manager for National Cylinder Gas Co., assisted by Lew Morris, Superintendent of the Evansville plant, entertained the group with a demonstration of the properties of liquid oxygen and the effect of its 297° F. below zero on various items. He even had a couple of boys talked into believing they had eaten a "cold-boiled" egg.

Some 40 members and guests were very delighted with Mr. Thuerbach's oxygen cork gun, miniature steam engine and other entertaining devices.

Welding of Aluminum

Springfield, Mass.—One of the best meetings of the season held by the *Western Massachusetts* Section took place on March 6th at Blake's Restaurant. W. M. Rogerson, head of the Welding Section of the Aluminum Company of America, Alcoa Process Development Labs., New Kensington, Pa., showed a film "The Welding of Aluminum," produced by the Aluminum Company of America, showing what happens to aluminum ore—bauxite—from the time it leaves the ground until it becomes a utensil, or one of the many articles for which the metal is used. Mr. Rogerson later demonstrated the technique of aluminum welding and brazing.

Plant Tour and Meeting

Wichita, Kan.—A plant tour of the new Coca-Cola Bottling Co. in operation was held by the *Wichita* Section prior to a buffet supper and meeting held on March 10th.

H. W. Beutel, AWS, Works Manager, Mosher Steel Co., Dallas, Tex., a highly interesting and dynamic speaker, and well accomplished on his subject, "This Business of Management," spoke extemporaneously on his broad experience gained through his years of association with the Steel Industry. Mr. Beutel showed how each one is affected by the current problems in management under our modern economy. He gave valuable information on what industry is facing today and what effect it will have on us as a group and as individuals.

A sound color film by the U. S. Steel Corp. on the construction of the United Nations Building in New York was also shown.

Flame Cutting

Worcester, Mass.—Richard Helmkamp, AWS, Machine Cutting Specialist, Air Reduction Sales Co., presented an excellent talk on "Flame Cutting" at the March 27th dinner meeting of the *Worcester* Section held at the Tower House.

An after-dinner feature was the showing of a film "Shining Rails—Canadian Pacific Railroad," which was shown through the courtesy of the Worcester Chamber of Commerce. This was an excellent sound color film.

A meeting of the Officers and Directors of the Section was held following the technical session. Present were: Messrs. E. Adams (District Vice-President), Burnett, Jamieson, Kasabula, Kenny, Jackson

Moore, Murray, Proctor, Polaski, Smith, Spellman, Walker and Wilson.

It was voted to hold the Annual Meeting and Ladies Night on April 30th.

The Chairman appointed an entertainment committee consisting of Messrs. George Wilson, C. Myron Burnett and Wesley Proctor.

The Chairman also appointed Messrs. J. Polaski, Ralph Holmes and John Kassbula as an auditing committee.

Welding Metallurgy

Youngstown, Ohio.—Dr. Robert D. Stout, AWS, Lehigh University, Bethlehem, Pa., was the speaker at the March 30th meeting of the *Mahoning Valley* Section. His research subject "Metallurgy of Welding" was excellently presented. The student body and faculty of the Metallurgical Department at Youngstown College were guests of the Section.

LIST OF NEW MEMBERS

Effective March 1, 1952

ANTHONY WAYNE

Mosser, Carl (B)

BOSTON

Duffy, John (B)
Loeffler, William A. (B)
Millett, Everett L. (B)

BRIDGEPORT

Renzi, Paul A. (C)

CHICAGO

Abromitis, Frank J. (C)
Chase, Harry (C)
Dalton, Freeman A. (C)
DeCoste, Joseph E. (C)
Fraser, Lewis H. D. (B)
Hemzacek, Edwin J. (C)
Hoff, William (C)
Kinsock, J. L. (C)
Larkin, James T. (C)
Maher, Frank A. (C)
Naef, U. G. (B)
Russell, Arnold A. (C)
Zeh, Richard F. (C)

CLEVELAND

Bailey, Oliver L. (B)
Beecher, William E. (B)
Dervaly, Albert P. (C)
Emmerman, Aaron (C)
Esterhay, Anthony S., Jr. (C)
Fackler, Simon E. (B)
Hudson, Oliver G. (C)
Moffett, Ralph C. (B)
Peabody, Richard F. (B)
Starkey, Arnold C. (B)
Szereto, John (B)

COLORADO

Krainik, Erwin (B)
Waugaman, John A. (C)

COLUMBUS

Gillett, Leslie Ernest (B)
Kunez, Frank, Jr. (D)
Martin, George E. (B)
Schott, Charles Eugene (D)
Smith, Oren R. (B)

DALLAS

Livingston, M. M. (B)
Moore, D. R. (B)
Smith, Robert A., Jr.-(B)

DAYTON

Gaylord, P. F. (C)

DETROIT

Craft, Luther O'Niel (C)
Evans, Lorin E. (C)
Field, Hugh J. (C)
Hahn, Jack O. (C)
Karl, Robert L. (B)
Murray, Jack W. (C)
Rhoades, Melville (C)

HARTFORD

Delisle, Leo A. (C)
Whitney, Burton O. (C)

HOUSTON

Arnold, S. E. (B)
Baker, Joe H. (B)
Bridges, Oscar P. (B)
Butterwick, Ward (B)
Davis, Hoyte W. (B)
Dwyer, B. M. (B)
Ehman, George L. (B)
Gabert, Lenard M. (B)
Gable, M. W. (C)
Haraldson, F. A. (B)
Hudson, Robert Donald (C)
Johnston, J. D. (B)
Martin, Joseph F. (C)
Matthews, R. O. (C)
Smith, R. P. (B)
Stephens, Ben, Jr. (C)
Thompson, Victor H., Jr. (B)
Van Sickle, Charles W. (B)
Weddle, Howell (B)

KANSAS CITY

Harwood, A. W. (C)

LONG BEACH

Derouchey, William T. (C)

LOS ANGELES

Marriage, Lawrence J. (C)
Miller, Ralph Kettler (C)

LOUISVILLE

Dozier, E. W., Jr. (B)
Hare, Chester A. S. (C)

MARYLAND

Rhode, Wilson Alvin (B)

MILWAUKEE

Maersch, Robert E. (B)
Turk, Joseph (C)

NEW JERSEY

Cook, Harry C. (B)
Steggall, Walter (B)

NEW YORK

Crowell, C. C. (C)
Geer, William H. (B)
Goldberg, Solomon (B)

NIAGARA FRONTIER

Bichsel, Harry J. (C)
Lassen, Wilbur H. (B)
Long, Byrns E. (B)
Roof, K. A. (C)

NORTHWEST

Braun, Carl H. (C)
Melink, George E. (C)

NORTHWESTERN PENNSYLVANIA

Lindquist, Knute T. (C)
Steva, Donald G. (B)

OKLAHOMA CITY

Pranter, Charles Theodore, Jr. (C)

PASCAGOULA

Johnston, William N. (C)

PEORIA

Barnes, Marvin T., Jr. (C)
Degitz, John H. (C)
Newell, Robert B. (B)

PHILADELPHIA

McDonald, H. D. (B)
Whitesell, W. G. (C)

PITTSBURGH

Mann, Robert D. (C)
Thomas, James F. (B)

PORTLAND

Frey, William D. (B)
Johnson, Carl (B)
Olsen, Thomas M. (B)
O'Neill, Waldo (B)

ROCHESTER

Curry, John L. (C)
Dibble, G. T. (C)

SAGINAW VALLEY

Sinclair, Harry (B)
Walt, Henry M. (D)

ST. LOUIS

Golterman, Paul Gene (C)
Roth, W. A. (B)

SALT LAKE CITY

Blakemore, A. B., Jr. (C)
Richeda, Fred (B)

SAN FRANCISCO

Harshman, Chet (B)
Lafferty, Robert J. (B)
Rhoton, Forrest (A)
Spellman, Jim (B)

SYRACUSE

Salisbury, Herman G. (C)

TOLEDO

Miller, Harold C. (C)

TULSA

Trimble, James R. (B)

WASHINGTON

Bailey, Fred C. (C)
Easter, Lyman F. (C)
Emory, Clarence W. (C)

WESTERN MASSACHUSETTS

Carroll, Charles W. (B)

WESTERN MICHIGAN

Cloyd R. L. (C)
Hendricks, Don R. (C)
Herman, Alphonse C. (C)

WORCESTER

Hedlund, Ralph V. (B)

YORK-CENTRAL PENNSYLVANIA

Brady, James C. (B)
Ruby, Philip C. (B)
Sanders, Robert Lee (C)

NOT IN SECTIONS

Bradley, Frank W., Jr. (D)
Chapman, Philip J. (B)
Cook, Lloyd A. (B)
Faist, Wesley E. (D)
Frala, Robert E. (D)
Lambert, Paul W. (D)
Matzinger, Guy A. (D)
Schmitz, John G. (B)
Thomas, Ernest Walter (B)
Ward, Arthur H. (C)

PERSONNEL

R. L. Browne Made Sales Representative

R. L. Browne of 10 Post Office Square, Boston, Mass., has been appointed by the Precision Welder and Machine Co. of Cincinnati, Ohio, effective Apr. 1, 1952, as sales representative in New England. Mr. Browne is a graduate engineer with many years of experience in metal fabrication, resistance welding application and sales work which fits him well to handle this new assignment.

Wasserman Heads National Sunday School Week Drive

Rene D. Wasserman, President of Eutectic Welding Alloys Corp., served as Chairman for the welding industry in the Eighth Annual Sunday School Week Drive, Apr. 14–20, 1952.

This year the program again paid tribute to the contributions made by the Sunday schools to our way of life. This week-long recognition of the labors of the Sunday schools was celebrated by all faiths through the leadership of the Laymen's National Committee, an all-faith, non-profit organization.

Wagner Appointed to Oxygen Industry Advisory Committee, N.P.A.

It was announced recently that J. F. Wagner, Vice-President of the Burdett Oxygen Co. of Cleveland, was appointed to the Oxygen Industry Advisory Committee of the National Production Authority, Washington, D. C. Mr. Wagner's appointment will be for a term ending Oct. 1, 1952.

Mr. Wagner, prominent in the compressed gas industry, is a holder of several other important positions in the industry. He is Secretary and a member of the Board of Directors of the Independent Oxygen Manufacturers' Assn., Secretary-Treasurer of the Cleveland Section of the AMERICAN WELDING SOCIETY, and is actively serving on various committees of the Compressed Gas Assn. and the International Acetylene Assn.

Industrial Public Relations Man Heads Ohio Conference

Edmond C. Powers, who began his industrial public relations career in arc welding in 1934 when he became director of public relations with The Griswold-Eshleman Co., Cleveland, has been elected general chairman of the All-Ohio Public Relations Workshop to be held in Cleveland, May 8th.

Powers has gained national recognition for his work in street lighting and in fostering teaching aid programs on compressed air power with engineering colleges. His work in arc welding includes extensive article writing, promoting award programs for arc welding reports, editing handbooks. In addition to editing four books on arc welding, he is editor of *Compressed Air Handbook*, production editor of *I.E.S. Lighting Handbook* and author of *Lighting and the Nation's Welfare*.

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1. Case Hardened threads are always protected from weld spatter and never exposed to damage in open or closed position.

2. The clamp body is cut from solid plate, thereby insuring extreme rigidity and giving great resistance to bending or twisting.

3. Heat treated chrome molybdenum alloy handle offers great resistance to bending.

23 stock sizes

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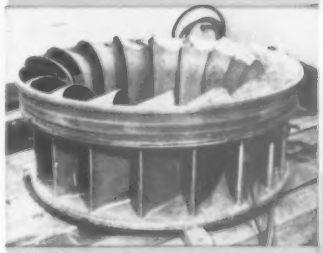
"Bronze-Facing" with Ampco* Electrodes Saves $4800



4-ton turbine runner "Bronze-Faced" with Ampco Electrodes.

Cavitation and erosion caused severe wear on the buckets and blades of this large 4-ton turbine runner. A new runner costs $6000. "Bronze-Facing" with Ampco Electrodes cost only $1200 — a savings of $4800!

Better Than New!

"Bronze-Facing" with Ampco Electrodes is used throughout industry to increase service life, provide superior bearing qualities, obtain improved resistance to wear and keep costs down . . . production up.

You too can save time and money by using Ampco Electrodes in your repair and maintenance operations. Get a supply today from your Ampco distributor, or write us.

Power company personnel preparing turbine runner for "Bronze-Facing" with Ampco Electrodes.

W-514

AMPCO
Ampco Metal, Inc.
Milwaukee 46, Wis.
West Coast Plant, Burbank, California
It's Production-Wise to Ampco-ize!
*Reg. U. S. Pat. Off.

NEWS OF THE INDUSTRY

Fiftieth Anniversary of the American Society for Testing Materials

Since its formal incorporation in the Commonwealth of Pennsylvania, Mar. 21, 1902, ASTM has concentrated its work on the promotion of knowledge of the materials of engineering and the standardization of specifications and the methods of testing. Even in this seemingly restricted field, the Society has found more than enough to occupy the attention of its officers, members and staff. This concentration of effort underlies, to some extent at least, the great influence of the Society.

Many have said that the ASTM technical committees are the heart blood of the Society. It is true that in these groups is concentrated great authority and autonomy for both standardization and research activities. Many exclaim at the complexities of the Society's committee structure and at the great output from the committees. Currently there are probably at least 2000 main committees, sections and related subgroups. Frequently at national meetings of the Society there will be over 500 committee meetings in a five-day period. One of the basic reasons for the widespread acceptance of ASTM standards is in the makeup of the technical committees which originate and draft standards. It is the rule that there shall be adequate representation by technical men representing both the producer and consumer, with a third independent or general interest group adequately represented.

Some of the technical committees are practically small societies in themselves and are quite large. Committee A-1 on Steel, organized in 1898, currently has over 350 men on its mailing list with over 150 standards in its charge.

In contrast to most of the professional and trade associations and societies which in a sense are a vertical type of organization, ASTM is frequently described as a horizontal type because its work cuts across all materials fields and the interests of many other trade and professional groups. This community of interest in standards and research in materials is recognized, for well over 100 leading societies and associations participate through official representation in the ASTM committee work; and there are numerous technical projects jointly sponsored; for example, automotive rubber (Society of Automotive Engineers); effect of temperature (The American Society of Mechanical Engineers); filler metal (American Welding Society); paper testing methods (Technical Association of the Pulp and Paper Industry); soap analysis (American Oil Chemists Society); textile methods (American Association of Textile Chemists and Colorists); etc.

In its long history the Society has had only two secretaries—Edgar Marburg, 1902–1918, and C. L. Warwick, 1919 to date. One of the founder members, Professor Marburg headed the Department of Civil Engineering, University of Pennsylvania, from 1892 until his death in 1918. Mr. Warwick studied under Professor Marburg, later was associated with him on the Pennsylvania Faculty, then was Assistant Secretary and succeeded Professor Marburg as ASTM Executive Secretary in 1919.

The present Headquarters Staff of about 60 occupies the Society's own building at 1916 Race St., Philadelphia 3, Pa., on the Parkway. Acquired in 1946, the building was financed through contributions from the members. Recently, the Society procured additional land adjacent to the building for pending expansion required by increased activity and larger Staff. The Philadelphia Academy of Natural Sciences flanks the Headquarters on one side and diagonally across Logan Square are the Philadelphia Public Library and the Franklin Institute.

Baldwin Gets Largest Stress Relieving Furnace

A new stress-relieving furnace has just been installed by Baldwin-Lima-Hamilton Corp. in its Eddystone plant. Built by the Industrial Power Equipment Co., Industrial Furnace Div., the 22,760 cu. ft. recirculated-air, convection-type furnace is the largest of its kind, and will be able to handle the massive weldments for hydraulic presses, hydraulic turbines and other specialties built by Baldwin. Physical dimensions are: length 60 ft. 5 in., width 22 ft., and height 17 ft. 1¾ in. The huge door is held closed by automatic cam-action clamps.

Indirect fired through three combustion chambers, controlled by Brown Instrument Co. temperature potentiometers, the furnace is also equipped with complete program control. Rate of heating, length of soaking time and rate of cooling are all set at the control board when the heat is begun.

Recirculated-air, convection-type heat-treating furnace

Each chamber has a high-temperature recirculating fan that pulls the gases from the furnace and forces them through the chamber for reheating. This eliminates fan burn-out since fan temperature does not exceed that of the furnace.

The furnace is equipped with 13 thermocouples for measuring the temperature of the piece being treated. They remain attached to the piece when the car is withdrawn from the furnace, the leads being connected to their instrument through a polarity plug on the car. On the first trial run, the furnace instruments recorded temperature differentials of only 5° F. on a 70-ton charge, which varied from 8 down to 3 in. in thickness.

General Electric Announces $200 Price Reduction on Atomic Hydrogen Welders

A list price reduction of $200 on atomic hydrogen welders has been announced by the Welding Dept. of the General Electric Co.

According to Raymond C. Freeman, manager of the department, the unit zone price reduction from approximately $1150 to $950 is the result of new and more efficient production techniques, plus a recent redesign of the equipment which made possible the utilization of parts used in other standard welding equipment.

The welder, rated at 75 amp., is 41½ in. high, has a diameter of 18¾ in. and weighs 350 lb.

Solar Machine Tools

Special precision machine tools, designed and built by Solar Aircraft Co. in its San Diego and Des Moines plants, are now being purchased by leading metalworking firms in Britain.

The Solar-built machines include special types of automatic inert arc butt-welding equipment; nibblers, which are used to trim the edges of complicated sheet steel shapes; and expanders, used to form tubular metal shapes; and a variety of others.

Helen Zamborik

Ten Years Behind the Mask—that's the story of petite Helen Zamborik, only woman welder in General Electric's Locomotive and Car Equipment Dept. at Erie, Pa. Although she weighs only 100 lb.,

FOR SPOT WELDING ALUMINUM

Improve quality of welds!
Increase number of spot welds before tip cleaning!
Prolong life of electrode tips!
Eliminate tedious, expensive mechanical cleaning!

DIVERSEY Pre-Welding Treatment for Aluminum

DIVERSEY No. 36 CLEANER
DIVERSEY No. 514 DEOXIDIZER

Be guided by this: Companies employing the Diversey Pre-Welding Treatment report increases up to 50% in spot weld output and increases in number of spot welds made before electrode tips require redressing!

If you are looking for improved spot welds, increased production and lower costs, it will pay you to investigate the famous Diversey Pre-Welding Treatment for aluminum now . . . it's practical, proved superior, easy and surprisingly economical to use!

Diversey Pre-Welding Treatment is possible because of two outstanding Diversey developments . . . No. 36 cleaner for removing identification markings, grease, soil and No. 514 deoxidizer for removing oxide and heat scale!

A Diversey D-Man will be happy to show you the advantages of Diversey Pre-Welding Treatment for aluminum! No obligation! Write today! Complete information is available!

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Mrs. Zamborik specializes in heavy equipment welding. The mother of two children, she started her welding career during the World War II man-power shortage. Above, she waves from the headlight opening of a new G-E locomotive cab.

Chloromycetin Plant Features Welded Equipment

A unique new manufacturing plant swings into operation this month. The first and only one of its kind in the world, it has been designed and built exclusively for the production of the life-saving drug Chloromycetin by chemical means.

So far, Chloromycetin—effective in combating more than 100 different diseases and pathogenic bacteria—is the only antibiotic that chemists have been able to build up synthetically. All of the others, like penicillin and streptomycin, are still being produced by fermentation.

The new Parke, Davis & Co. Chloromycetin plant, located in the Dutch community of Holland, Mich., will more than double the 85 year-old drug firm's capacity for producing the widely used antibiotic, according to Harry J. Loynd, the company's president.

In order to build up the Chloromycetin molecule on a chemical production line basis, more than a million dollars' worth of special large-scale chemical equipment has been installed. The main processing building—longer than a football field and with a 40-ft.-high ceiling—houses an array of giant-size, glass-lined and stainless steel vats, stills, evaporators, storage tanks,

Fig. 3 This giant twin-shell dry blender readies the Chloromycetin for capsuling

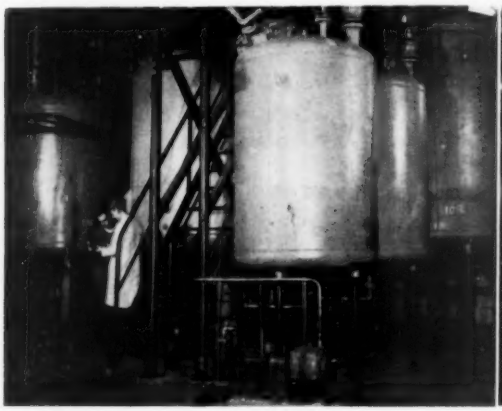

Fig. 1 Special large-scale equipment is required in the complicated chemical process by which the Chloromycetin molecule is built up at the unique new plant of Parke, Davis & Co. at Holland, Mich.

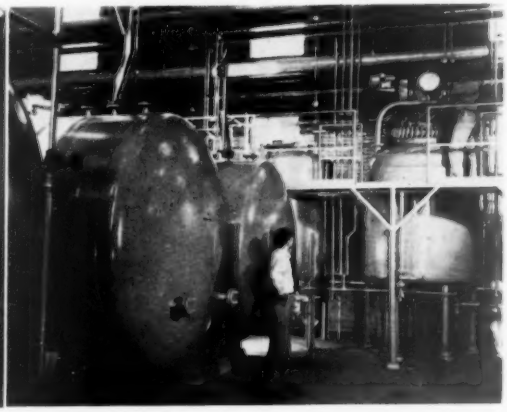

Fig. 2 Massive welded storage tanks and vacuum stills play an important part in the tricky chemical processes

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THE DYE PENETRANT METHODS
IT'S NEW! CHEK-SPEK
HERE'S TURCO'S NEW PRODUCTION-LINE METHOD OF FLAW LOCATION...SIMPLE, SAFE & ACCURATE. SAVES YOU MONEY & TIME!
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LASTING VISIBILITY OF FLAW INDICATIONS PERMITS ECONOMICAL RE-WORKING AT YOUR CONVENIENCE.
RE-WORK WELDERS SAY
MAKES EACH JOB EASIER BECAUSE WE CAN SEE WHERE THE DEFECTS ARE!

filters and reactor kettles. The amount of pipe, tubing and conduit used to route the chemicals and control the process if joined together in a line would stretch completely across the broad state of Michigan from Holland to Detroit! More than four miles of aluminum tubing alone have been used to connect a buried 124,000-gal. "tank farm," where special chemical solvents used in the process are stored, to the measuring gages in the plant's control room.

Much of the equipment used in this new plant is of all-welded construction, as shown in Figs. 1 to 3.

Steel Saver

The steel saved in this bridge across the Rhine River in Cologne, Germany, is typical of what the Lincoln Foundation is trying to stimulate with its current Welded Bridges for Steel Conservation Award Program.

The bridge replaces one which was destroyed in the last war. The old bridge used 8500 tons of steel whereas the new one uses only 5639 tons. Even with this 30% saving in steel the new bridge has greater capacity than the old one. It was designed by Dr. Ing. F. Leonhardt, and is made up of a series of steel box girders, varied in depth to form shallow, parabolic curves. Spans are 404 + 605 + 407 ft.; cellular welded structure with D at crown $L/60$; roadway is 38 ft. with two 10-ft. sidewalks. It is claimed to be the longest full-web continuous girder bridge in the world. (*Transactions*, South African Institute of Civil Engineers, June 1951.)

Fabrication of Power Recovery Turbines

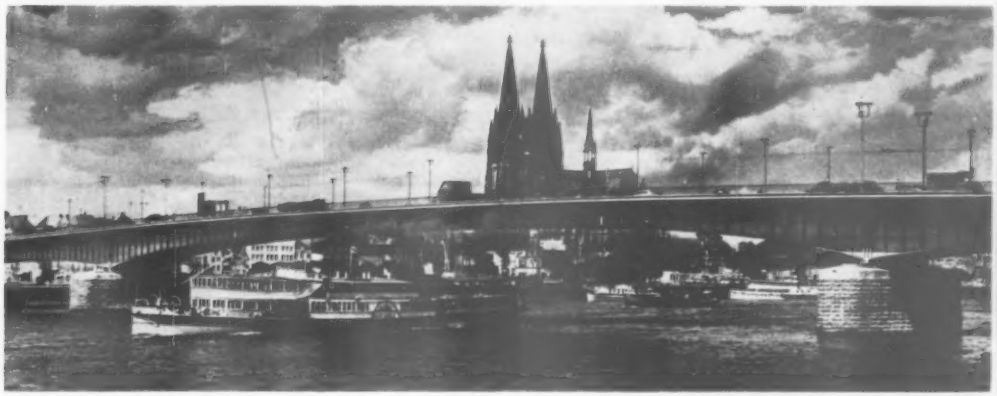
Fabrication of power-recovery turbines for aircraft engines has been accelerated and production costs lowered by use of an internally water-cooled Inert Arc welding torch at the McGregor Manufacturing Corporation of Birmingham, Michigan.

According to McGregor engineers, use of a General Electric inert-arc torch has saved at least 25% in gas consumption over previous equipment used in this defense-vital operation. In addition, they said, downtime for adjustment of tungsten electrodes was reduced, and consumption of the tungsten was curtailed due to more efficient gas consumption through new nozzle design. An efficient internal water-cooling system, they said, has also reduced tungsten consumption and provided a more stable arc.

In its work on power recovery turbines, the McGregor Co. welds an Inconel part to a cast stainless steel base. This welding operation is shielded from behind by

sealing up the ends of the power recovery turbine and maintaining helium pressure at 22 psi. through a tap.

Another of the company's mass production jobs in which the same welding techniques are utilized is welding of piston-rod guides to piston-rod crossheads. In this operation, No. 347 stainless steel is the parent metal and $^1/_{16}$-in. diameter No. 347 stainless steel welding rod is the filler metal.



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KEEPS ACCEPTABLE PARTS MOVING...ONLY SUSPECTED PARTS GO TO TRAINED INSPECTORS. SIMPLIFIES EVALUATION, CUTS DEPARTMENT COSTS.
PRODUCTION SUPTS. SAY
ELIMINATES INSPECTION BOTTLENECKS. PERMITS ONE MAN TO CHECK AS MANY PARTS PER HOUR AS HE CAN PICK UP AND PUT DOWN!
PLANT MANAGERS REPORT
SAVES IN-SHOP-HANDLING TIME. PERMITS IN-PROGRESS INSPECTIONS. AN EXCELLENT RECEIVING DEPARTMENT TOOL. YOUR PEOPLE WILL LIKE IT!

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Simply staple coupon to company letterhead

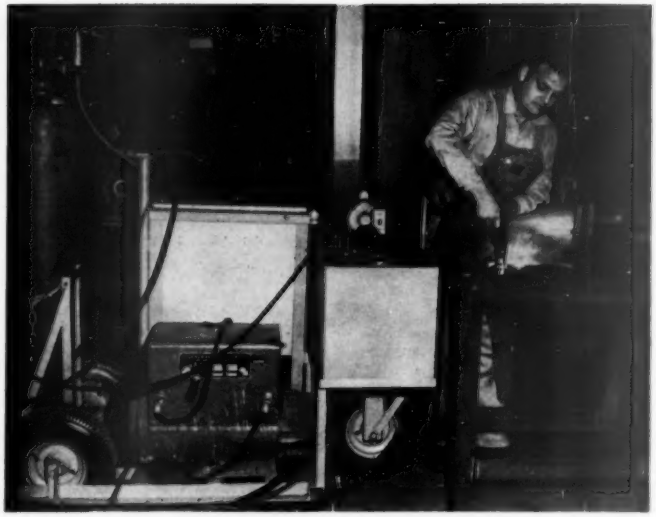
Inert-Gas-Shielded Arc Welding Equipment Set on Wheels

Plant engineers of the Ryan Aeronautical Co. have harnessed the Linde heliarc spot-welding gun to a mobile machine which multiplies its usefulness. The Ryan-designed equipment package can be rolled to any production point and placed in operation within a matter of minutes.

The inert arc welding process has many advantages for spot welding. It is exceptionally clean and does not involve the use of flux. Consequently, there is no flux removal problem. It does not produce a build-up or erosion of metal but leaves a smooth surface which requires no grinding or finishing. Spot welds thus made can be run between seam-welding wheels without surface preparation.

The Linde pistol-grip welding gun brings the advantages of inert arc welding to the spot-welding process because it provides accurate timing control not possible to achieve manually. It is extremely light weight and compact and can be used for spot welding sheet metal and machined members in their assembly jigs because it spot welds components which are accessible from only one side. This eliminates the time-consuming job of removing these structures to welding machines and permits the spot welding of large or irregularly shaped assemblies which would not be accessible to fixed electrodes.

The new Ryan machine, which was suggested by Ray Ortiz, Manifold Production Superintendent, provides the welding



gun with all of the necessary facilities in a compact, mobile unit. It incorporates a timing control, d.-c. generator, argon gas supply and 40-gal. water tank and pump. Operation of the equipment is completely automatic from the time the operator presses the trigger.

First, argon gas flows through the cable to the gun and out the barrel, blanketing the weld zone with a protective gas envelope. Then, a d.-c. current, with a superimposed high-frequency a.-c. current, is fed to the gun's single tungsten electrode. The arc strikes for an exact interval which is sufficient to cause the metals to heat and flow together. At its termination, the argon gas continues to flow for a few seconds to protect the electrode against oxidation while still hot. Cooling is provided by water which is circulated through the gun by an electric-driven pump from a 40-gal. supply.

LIL CHAMP
ALRIGHT, JOE, LET'S FACE IT! WE'RE BACK IN IT AGAIN AN' EVERY MINUTE COUNTS! WHAT CAN WE DO TO START THE BALL ROLLING—PRODUCTION CONTROL SAYS WE HAVE ALL THE MEN AN' MATERIALS FOR TOP OUTPUT, YET WE'RE BEHIND SCHEDULE. WHAT GIVES!!!
OFFICE
IT'S FINAL ASSEMBLY IN THE WELDING DEPARTMENT- WE CAN'T GET ALL THE WORK OUT AN' MAKE REPAIRS ON REJECTS AT THE SAME TIME!
BOYS, THOSE CHAMPION GRAY DEVIL No.2 ELECTRODES DID THE TRICK! PRODUCTION IN OTHER DEPARTMENTS MUST INCREASE JUST TO KEEP THE WELDING DEPARTMENT ROLLING!
WELDING IS NO LONGER OUR BOTTLENECK- NOT SINCE WE PUT CHAMPION GRAY DEVIL No. 2 ELECTRODES TO WORK FOR US!
WHEN SMOOTH BEADS, LOW SPATTER AN' GOOD PRODUCTION RATES ARE NECESSARY THAT'S WHEN YOU NEED CHAMPION GRAY DEVIL No.2. ELECTRODES! EXCELLENT ARC-STRIKING CHARACTERISTICS AND ITS ABILITY TO OPERATE ON HIGH WELDING CURRENTS MEANS FASTER WELDING AT LOWER OPERATING COSTS. WHEN WELDING— USE THE BEST—USE CHAMPION GRAY DEVIL No.2!!
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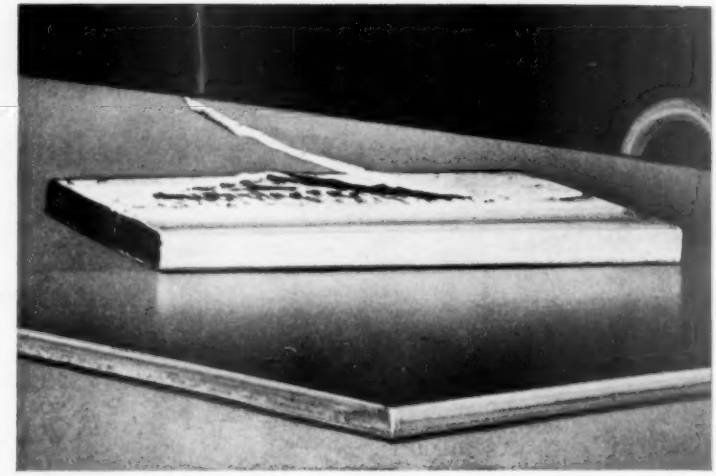

This weld in Nickel-Clad Steel shows the self-lifting slag which the "141" nickel electrode gives when there is a proper balance in the welding conditions.

New Inco Electrode for Nickel-Clad Steel

"141" Nickel Electrode makes possible high ductility in iron-diluted nickel welds

The new Inco "141" nickel electrode for Nickel-Clad Steel is a companion to the Inco "131" nickel electrode for solid Nickel. Its new core wire and new flux make it possible to obtain high ductility when welding the clad side of Nickel-Clad Steel... overlaying nickel on steel ... welding nickel to steel.

"141" is corrosion-resisting. Welds made with the "141" electrode on Nickel-Clad Steel or overlays on steel will have corrosion resistance comparable to that of solid nickel, providing adequate control is exercised over the iron dilution of the welds.

"141" meets Code requirements. Welds made with the "141" nickel electrode meet the requirements of the A.S.M.E. Unfired Pressure Vessel Code for construction of units covered by Case 896 (Clad Steels) and Case 1078 (applied linings).

Slag removal is easy, too. When the balance between heat input, speed of welding and iron dilution is right, the slag will lift from the weld about 3 inches behind the arc.

Mechanical Properties

(a) Nickel overlays on steel will have a minimum elongation of 30 per cent.

(b) Welds in the clad side of Nickel-Clad Steel will have a minimum elongation of 30 per cent.

(c) Welds in solid nickel will have a minimum elongation of 20 per cent.

(d) All weld metal tensile specimens (iron free) have the following properties:

Minimum yield strength (.2% offset) .....30,000 psi.
Minimum tensile strength .....65,000 psi.
(Hardness) Rockwell B 70-80

Like other Inco products, much of the "141" electrode production is being diverted to defense at present. However, Inco's Technical Service Section is always ready to help you with ideas and suggestions for your present production and future planning.

Write today, outlining your problems. Also, ask for your free copy of revised Inco Bulletin T-2, "Fusion Welding of Nickel and the High-Nickel Alloys."

INCO TRADE MARK

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American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers
American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers

Supplement to the Welding Journal, May, 1952

Preheat vs. Low- and High-Temperature Stress-Relief Treatments

Test results on large specimens designed to give a direct comparison of preheat, low-temperature stress-relief and postwelding heat treatment at 1200° F.

by E. Paul DeGarmo

IT IS A healthy condition when the proponents of any fabrication process seek new ways of improving the performance of parts or structures which they make. Since its beginning the welding profession has thus sought procedures whereby the performance of weldments could be improved. It was recognized at an early date that a steel plate containing a weld does not perform as well, under most conditions, as one which has not been welded. This is particularly true when notches or low temperatures are encountered. Early investigators found that if a weldment was annealed at 1700–1800° F. virtually all of the properties of the virgin plate would be restored. Unfortunately, such a heat treatment is not practicable for most weldments since at this temperature range considerable distortion or partial collapse of the weldment will occur and serious scaling result unless a controlled atmosphere is used. Because of these difficulties a compromise heat treatment has been widely adopted. This consists of a postwelding heat treatment at 1200° F. followed by relatively slow cooling, usually in the furnace. Numerous investigations and many experiences have shown that such a treatment produces a weldment which performs nearly as well as the unwelded parent plate. This type of heat treatment is specified in several codes.

E. Paul DeGarmo is Professor of Mechanical Engineering with the University of California.

Such heat treatment is fairly expensive and in many cases cannot be used because of weldments being too large to be put into any available furnace. Because of these limitations several alternative treatments have been devised and advocated. The author and his colleagues in 1947 reported the results of tests made on large hatch corner type specimens welded with 400° F. preheat and compared with specimens which were given a 1000° F. postwelding heat treatment for 8 hr.[1] In these tests the performance of the preheated specimens was slightly better than the one which had postheat. From the results of these tests it appeared that the simpler and less expensive preheat at 400° F. might be an effective substitute for the high-temperature postwelding treatment.

In 1948 T. W. Greene reported the results of some extensive tests wherein the performance of weldments which had been furnace stress relieved at 1200° F. were compared with identical weldments which had been given a "controlled, low-temperature stress-relief" treatment.[2] This latter treatment consists, essentially, of heating the compression zones parallel to the weld to approximately 350° F. while the weld is kept cool, thus thermally stretching the weld. Greene's results showed that the weldments which were given the low-temperature stress-relief treatment performed markedly better than as-welded specimens but not as good as those which received the 1200° F. postweld heat treatment.

While some of the conclusions reached by Greene as to the reasons for the improvement which resulted from the low-temperature treatment are highly debatable, there is no question but that the process does considerably improve the performance of weldments, at least under many conditions, and thus the procedure is another possible substitute for postwelding heat treatment at high temperatures.

In several other instances comparisons have been made between preheated and high-temperature stress-relieved weldments, and between controlled low-temperature and postwelded high-temperature stress-relieved weldments. However, there do not appear to have been any tests which would give a direct comparison between all three of these possible methods of treatment, namely (*a*) preheat, (*b*) "controlled low-temperature stress relief" and (*c*) postwelding heat treatment at 1200° F. The tests described herein were designed to give a direct comparison of the results which can be obtained by these three methods of treatment, using a specimen large enough to contain the maximum amount of residual stresses. It was believed that this last feature was desirable since although nearly all evidence points to residual stresses not having appreciable effect in the performance of weldments, some have doubts about this and one of Greene's conclusions was that the improvement obtained by the controlled low-temperature treatment was largely due to the decreased residual stresses which resulted.

PROCEDURE

The specimens and method of testing used by Greene have many excellent features. This specimen consists of two $^3/_4$-in. plates, 18 by 30 in., joined along their 30-in. edges by a butt weld, using a single-V edge preparation. These specimens are large enough to permit maximum residual stresses to be obtained and also to permit a variety of treatments. Greene produced a rather novel notch in his specimens by making fine jeweler's saw cuts back from the root face of the bevel in each plate at the mid-length of the prepared edge. In at least some of the specimens it was found that transverse cracks occurred in the weld beads at the location of these saw cuts. These formed fine and "natural" notches in the weld. However, it does not appear that the resulting notch was actually identical in each specimen. For this present series of tests, therefore, the notch was produced by first smoothing off the weld bead on the root side at the center of the joint until it was flush with the surface of the plates and then feeding a $2^3/_4$-in. diameter Charpy V notch cutter into the weld bead to a depth of 0.025 in., making this notch on the root side of the weld and transverse to the weld length. While the resulting notch was not as sharp as that obtained by Greene, it could be exactly reproduced in each specimen. Other than this difference in notches the specimens, shown in Fig. 1, were the same as used by Greene.

Eight specimens were made and tested as follows:

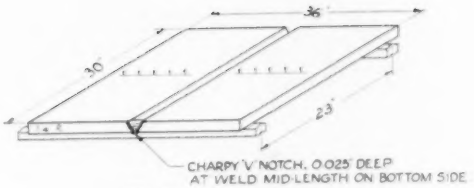

Fig. 1 Bend test specimen

Specimens 1 and 2, as-welded; specimens 3 and 4, 400° F. preheat; specimens 5 and 6, stress-relief heat treatment at 1200° F.; specimens 7 and 8, controlled low-temperature stress relief.

The plate material was ordinary semikilled carbon steel having the following analysis: Carbon 0.233%, sulphur 0.035%, phosphorus 0.004%, manganese 0.72%, silicon 0.03%, chromium 0.05%, nickel 0.05%, copper 0.02% and aluminum 0.01%.

All welds were made with AWS E-6010 type electrodes. Except in the case of the preheat specimens the weldments were allowed to cool to below 80° F. between passes. All passes were made from one end of the seam and completed before starting the next pass. In making the preheat specimens the plate within 6 in. of the weld was maintained at 400° F.

All stress-relief treatments, both high and low temperature, were done on the second day after the specimens were welded. Each specimen was tested on the second day following welding or heat treatment.

Specimens 7 and 8 were relieved by the controlled low-temperature procedure, using 350–400° F. in the

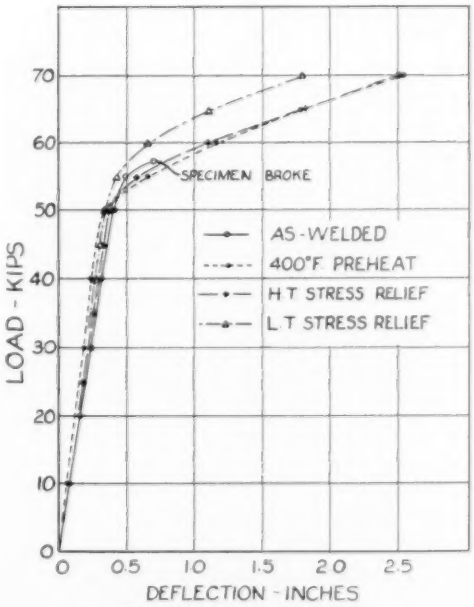

Fig. 2 Load-deflection curves

Fig. 3 Macrographs of welds in four specimens

heated zone with 15 in. per minute flame travel speed.

Specimens 5 and 6 were heated and held at 1200° F. for 1 hr. and then allowed to cool in the furnace.

All of the specimens were tested in bending, as indicated in Fig. 1, at a temperature of −80° F.

RESULTS

The results of the bend tests are shown by the load-deflection curves in Fig. 2. Each curve is the average of two specimens. The scatter between the two specimens of each type was very small. It will be noted from these curves that only the as-welded specimens fractured. In the other tests the loading was stopped at 70,000 lb. since at this load the deflection at the center of the specimen was as great as the specimen supports would allow.

It is apparent that all of the specially treated specimens performed much better than those in the as-welded conditions. The performance of the preheated specimens was almost identical with and just as good as that of those which had been stress relieved at 1200° F. The specimens which had been given the controlled low-temperature stress-relief treatment gave much better performance than the as-welded specimens but did not exhibit as ductile behavior as either the preheated or high-temperature stress-relieved specimens.

The reasons for the improvement in the performance of the specimens which were treated in the three special manners are not completely known. One factor which may partially account for the improved performance of the preheated specimens is shown in Fig. 3. Here it is apparent that the heat-affected zone of the preheated specimen is much wider than the corresponding zones of the others. The boundaries of the heat-affected zone of this specimen are also much less sharp. Thus there is a less severe transition from the parent metal to the heat-affected zone and on to the weld metal. That

Fig. 4 Photomicrographs of as-welded specimen

Fig. 5 Photomicrographs of preheated specimen

Fig. 6 Photomicrographs of high-temperature stress-relieved specimen

Fig. 7 Photomicrographs of low-temperature stress-relieved specimen

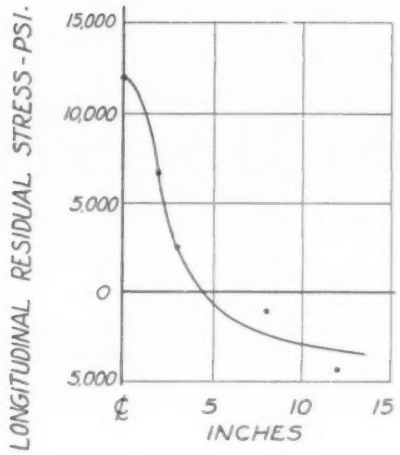

Fig. 8 Longitudinal residual stresses in preheated specimen

this transition is also less sharp from a metallurgical sense is also shown in Figs. 4, 5, 6 and 7. In Figs. 4 and 7, the change in microstructure from parent metal to heat-affected zone and from heat-affected zone to weld metal is quite sharp and essentially the same in both the as-welded and low-temperature stress-relieved specimens. In the preheated and high-temperature stress-relieved specimens, shown in Figs. 5 and 6, the change from weld metal to heat-affected zone is considerably less abrupt and from heat-affected zone to parent metal it is very gradual, particularly in the preheated specimen.

Microhardness measurements did not show any appreciable differences in maximum hardness in the as-welded, preheated and the low-temperature stress-relieved specimens. The high-temperature stress-relieved specimens of course were considerably softer.

Since there does not appear to be any metallurgical change as a result of the controlled low-temperature stress-relieving process, which is to be expected from the temperatures used, one naturally must seek other reasons for the improvement in performance which results from the use of this process. Undeniably the residual stresses which remain in weldments treated by this process are low. Greene[2] reports them as less than 5000 psi. and attributes the improved performance to this absence of high stresses. Residual stress measurements were made on a preheated specimen, identical to specimens 3 and 4. The maximum residual stress was 12,000 psi. as shown in Fig. 8. This is a lower value than would be found in a preheated weldment of larger size since the preheat was relatively less localized than it would be in a larger weldment. However, the residual stresses in the preheated specimens were undoubtedly greater than in the low-temperature stress-relieved specimens and yet they performed much better. Also it is significant that in the hatch corner tests, mentioned previously, which were very large, the performance of preheated specimens was equal to, or better than, that of high-temperature stress-relieved specimens. Thus it appears doubtful if the improvement in performance obtained when the low-temperature stress-relieving process is used is due to the virtual absence of residual stresses. There does not as yet appear to be a satisfactory explanation.

CONCLUSIONS

From these tests the following conclusions appear to be justified:

1. The use of preheating at 400° F., postwelding heat treatment at 1200° F., or controlled low-temperature stress relief produces marked improvement in the performance of weldments under static load conditions.

2. The results obtained by 400° F. preheat are as good as those obtained by 1200° F. postwelding heat treatment.

3. Controlled low-temperature stress relieving does not improve weldment performance as much as either 400° F. preheating or 1200° F. postwelding heat treatment.

4. The microstructure obtained by the use of 400° F. preheat is very nearly the same as that resulting from 1200° F. postwelding heat treatment but the heat-affected zone is wider.

5. The sharpness of the transition between the parent metal and the heat-affected zone and between the heat-affected zone and the weld metal is less in weldments which have 400° F. preheat or 1200° F. postwelding heat treatment than in as-welded weldments or those treated by the controlled low-temperature stress-relieving process.

6. Consideration needs to be given, by various code-making agencies to allowing 400° F. preheat to be used as a substitute for the conventional 1200° F. postwelding stress-relief treatment.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Charles Lockrem and John Harman for their considerable assistance in conducting these tests.

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1. DeGarmo, E. Paul, Meriam, J. L., and Grassi, R. C., "Some Tests of Large Welded Structures," THE WELDING JOURNAL, 26 (5), 257-s to 267-s (1947).

2. Greene, T. W., "Evaluation of Effect of Residual Stresses," *Ibid.*, 28 (5), 193-s to 204-s, (1949).

Repeated Load Tests on Welded and Prestrained Steels

This paper is one of a series resulting from a project sponsored by the Pressure Vessel Research Committee of the Welding Research Council. The project has as its object the study of the effects of fabrication operations on the mechanical properties of pressure vessel steels

by Sadun S. Tör, Jan M. Ruzek and Robert D. Stout

INTRODUCTION

PRESSURE vessels are generally subjected in service to some type of cyclic loading which may total during the lifetime of the vessel anywhere from several hundred cycles to several million cycles. This loading may be normal to the function of the vessel or it may occur accidentally by variations in the service conditions, thermal strains, or actual misuse (or abuse) of the vessel. If the loading is abnormal, it is apt to be higher than the design level and may produce plastic deformation in local areas containing stress concentrations. Eventually, such repeated overloading can result in failure of the vessel.

A study of the resistance of pressure vessel steels to repeated overloading does not involve fatigue testing of the usual type. No endurance limits are determined, since the levels of loading are in all cases above the yield strength of the material and produce failure in 100,000 cycles or less. The Fabrication Division of the Pressure Vessel Research Committee directed the project group at Lehigh University to study the effects of such fabrication operations as cold forming and welding on the resistance of pressure vessel steels to repeated overloading.

DEVELOPMENT OF THE TESTING METHOD

Specimen Design

There were two principal factors to be considered in the selection of a specimen design for repeated load testing. First, it was desirable to test the full plate thickness rather than some arbitrary portion of it. Second, the test section of the specimen had to be large enough to include a weld bead and the heated zone adjacent to it. This meant that the test section had to be $^5/_8$ in. thick (the plate thickness) and at least one inch wide. Under these circumstances it was best to load the specimen in bending in order to keep the magnitude of the loads required for plastic deformation within reasonable limits.

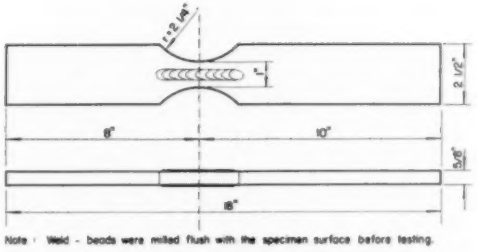

Fig. 1 Repeated load test specimen

The specimen was designed as shown in Fig. 1. It was loaded as a cantilever beam with the reduced section near the stationary grip. The surface of the specimen was the original plate surface; and when weld beads were applied, they were machined flush with the surface before testing.

Machine Design

The repeated-load machine was designed and built at Fritz Laboratory. Figures 2, 3 and 4 show different views of the machine. The design permits the application of either constant loads or constant deflections by the use of a coil spring or a solid link between the horizontal bars.

The machine was designed to the following specifications: loads up to 600 lb. and deflections up to 4 in.

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Paper was presented at the Thirty-Second Annual Meeting, AWS, Detroit, Mich., week of Oct. 15, 1951.

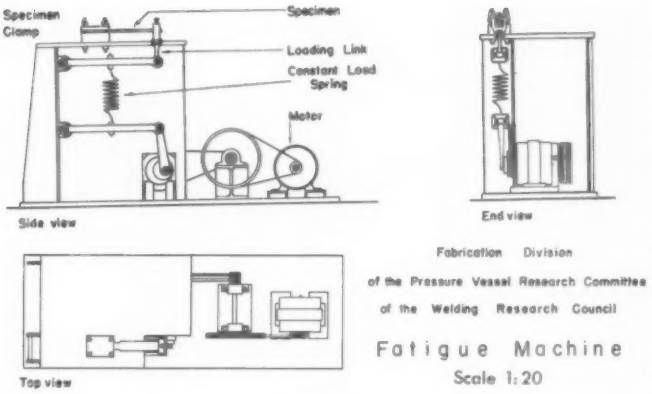

Figure 2

preferable to constant deflection as a loading method, since it would better simulate service conditions. Other factors soon became apparent, however, to change this viewpoint, and constant deflection was used for the test program. These factors were as indicated below.

In Fig. 7 the chief factor in favor of constant deflection is made evident. The load on the specimen is plotted against the deflection of the specimen at the loading end. Note that the load rises linearly to about 300 lb., corresponding to the yield point of the outer fibers of the specimen, then slopes off rapidly to about 400 lb. and thereafter remains virtually constant. Such behavior, which is characteristic of plastic bending, makes it impractical to use the load as an index of the severity of deformation imposed on the outer fibers of the specimen. At least this is true for loading conditions which produce failure in the range of 2000–100,000 cycles significant to pressure vessel service.

A second factor is the work hardening that takes place in the test section. With constant load, the deflection of the specimen decreases noticeably as cycling continues. Decreased deflection corresponds to decreased strain in the test section. While this effect is probably present in service, it is so sensitive to the ge-

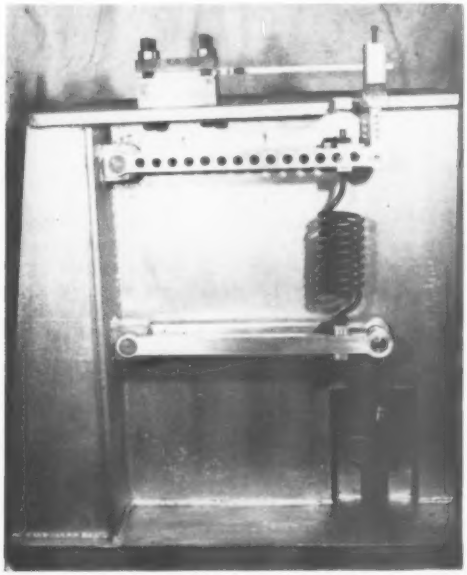

Fig. 3 View of repeated load machine showing constant-load spring link in position

at the movable end of the specimen, cycle speed between 100 and 400 cycles per minute, an automatic power cutoff at specimen failure, and a revolution counter.

Calibration of the machine was obtained by affixing strain gages to the loading link, as in Fig. 5, and a dial gage visible in Fig. 6. The loads and deflections applied to the specimen were correlated with the settings on the graduated eccentric of the crank arm.

TESTING PROCEDURE

Loading Method

It was first thought that constant loading would be

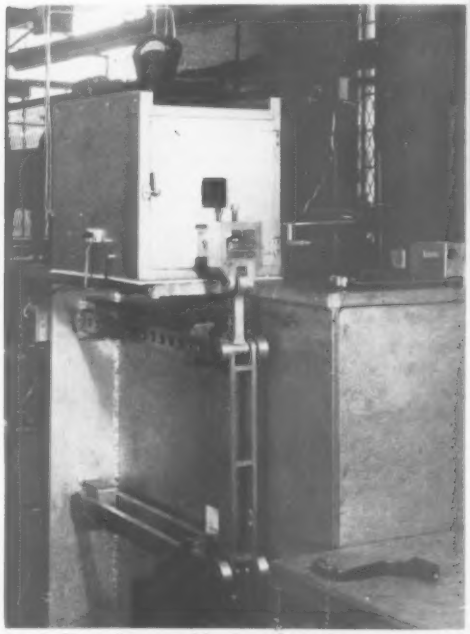

Fig. 4 View of repeated load machine showing solid link for constant deflection and furnace for tests at 500° F.

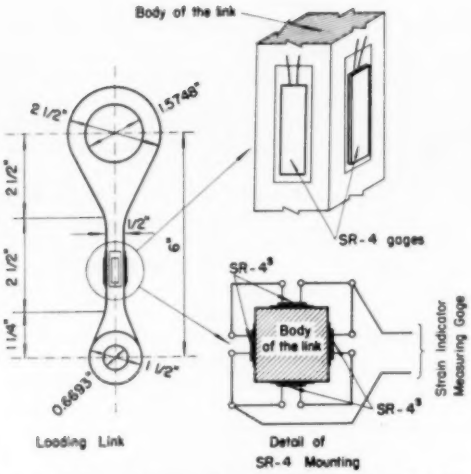

Fig. 5 Schematic connection of Sr-4 gages on calibration link

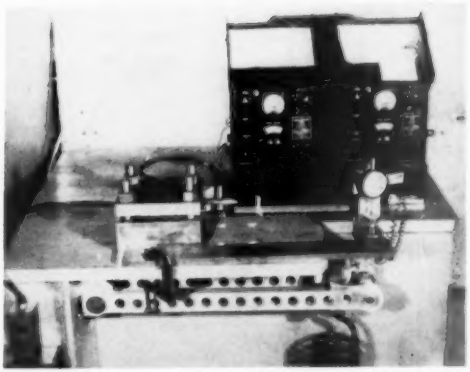

Fig. 6 Arrangement of SR-4 strain gages on the specimen and loading link, and the deflection dial gage for calibration of the machine

ometry of the section that there is little likelihood that the specimen conditions match service conditions. With constant deflection it was possible to introduce a known, relatively constant plastic strain for the period of cycling preceding crack formation. In accordance with these factors, constant deflection was used throughout the investigation.

Calibration of Strains

In order to establish settings on the cam eccentric which would produce desired levels of strain in the test section it was necessary to calibrate the machine and the specimen. For this purpose $^1/_4$-in. SR-4 strain gages were cemented on both top and bottom surfaces at the throat of the specimen to measure the strain at the outer fibers as a function of the specimen deflection, which is indicated by the dial gage and regulated by the cam setting.

"In Fig. 8 calibration curves are presented for as-received A-201 steel on the first loading cycle and also for A-201 steel after 200 cycles and after 700 cycles. A constant deflection was used for all cycles and all recorded strains were measured in the extreme fibers of the throats of the specimens by means of SR-4 gages with a longitudinal base length of $^1/_4$ in. It will be noticed that the measured strain for the same load decreased after cycling. This was due to work hardening of the throat which forced unworked metal adjacent to the narrowest section to contribute part of the total strain

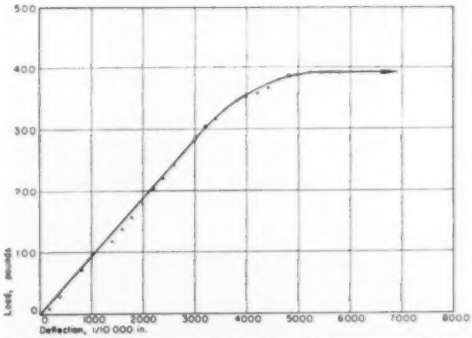

Fig. 7 Relation of the deflection of the repeated load specimen to the load applied

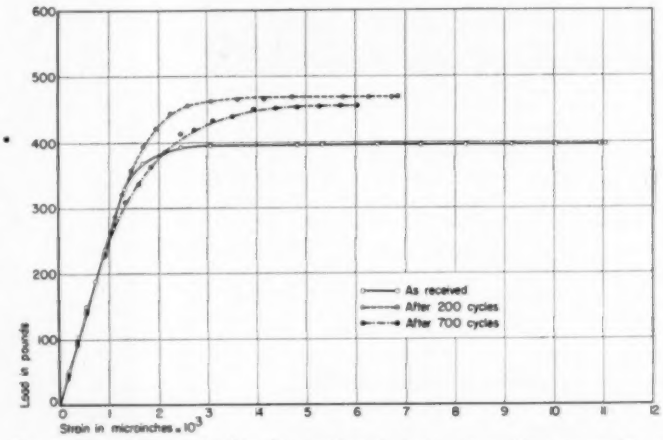

Fig. 8 The relation of load to the strain at the test section of the repeated load specimen

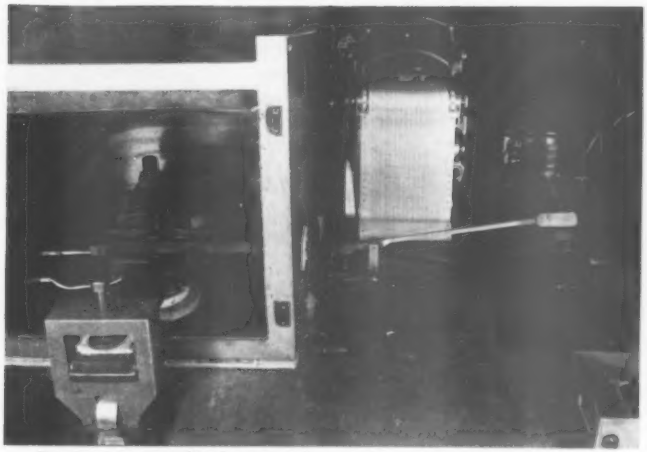

Fig. 9 Apparatus for detecting the endpoint of the repeated load tests

without registering it on the SR-4 gages. For the test program each strain level selected was defined as the strain measured by means of the SR-4 gages during the initial cycle of loading."

Endpoint of Testing

Originally the machine was designed to shut off when the specimen broke into two and so fell on a microswitch feeding into the power relay switch. It was found that frequently the specimen would fail except for a paper-thin section which would hold together sometimes for a dozen, sometimes for several hundred cycles. This action contributed needless scatter to the results.

It was decided to define the endpoint of the test as that at which the load carrying capacity of the specimen dropped to a small fraction of the original value. This was accomplished by the device pictured in Fig. 9. A magnifying lever was rested on the end of the throat section nearest the stationary clamp. A small elastic movement in the specimen at this point actuated a flag between a light source and a photronic cell. The light reaching the cell varied directly as the amount of movement of the flag, and the voltage output of the cell was fed to a d.c. amplifier, the output of which was recorded on an Esterline-Angus voltmeter. When the throat of the specimen was cracked sufficiently, it no longer communicated load to the fixed end and the flag movement became small, as did the output voltage to the recorder. By this method, the endpoint of the test could be recorded without constant attendance of an operator.

Test Conditions

A pilot series of tests was made to determine the strain levels which would result in failure in the range of 1000 to 100,000 cycles of loading. These were found to be between the yield point and 1% total strain. Four levels of strain for testing were then established: 0.15, 0.4, 0.7 and 1.0%. Each test run was conducted with triplicate specimens or twelve specimens to each series. Reversed bending was imposed on all of the specimens, the opposite deflections being equal.

Since loading in the plastic range produces measurable heating of the specimen, the cycling rates were limited to values which did not heat the specimens above 125° F. The speed ranged from 100 cycles per minute for 1.0% strain to 375 cycles per minute for 0.15% strain.

While most of the tests were conducted at room temperature, some of the test variables were investigated by cycling at 500° F. A furnace with an auxiliary heating unit was mounted on the machine to enclose the stationary clamp and the throat of the specimen. The temperature was controlled by fastening a thermocouple to the throat of the specimen and by it controlling the auxiliary heater under the throat. The experimental setup is shown in Fig. 10.

THE VARIABLES STUDIED

The Steels

The steels used in this investigation were $^5/_8$-in. thick plates of two pedigreed heats obtained at the start of the project. One was aluminum-killed A-201 and the other was rimmed A-285 of the following analyses.

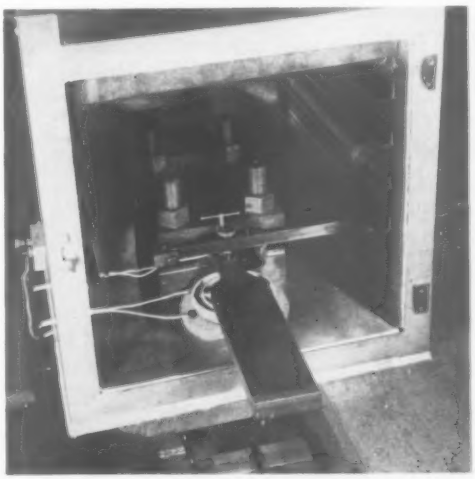

Fig. 10 Furnace and auxiliary heater used for tests at 500° F.

Steel Analyses

	C	Mn	Si	P	S	Cr	Ni	Cu
A-201	0.15	0.53	0.20	0.020	0.022	0.04	0.05	0.07
A-285	0.20	0.35	0.02	0.019	0.028	0.04	0.10	0.14

Average Tensile Properties as Rolled

	Upper yield point, psi.	Lower yield point, psi.	Tensile strength, psi.	Elongation, %	Reduction of area, %
A-201	36,000	35,000	60,000	32	62
A-285	34,000	32,500	58,000	31	59

Tests were on strip tensile specimens.

The steels were received in the as-rolled condition. All specimens were cut out with their long axis parallel to the rolling direction.

Treatments Before Testing

Tests at Room Temperature—The two steels received before testing a series of treatments which are listed below:

1. Heating to 75, 500 or 1150° F.
2. 10% tensile straining parallel to the rolling direction, followed by heating to 75, 500 or 1150° F.
3. 10% tensile straining transverse to the rolling direction, followed by heating to 75, 500 or 1150° F.
4. Longitudinally bead-welding on both sides with E6020 electrodes at 175 amp. and 10 in. per minute followed by heating to 75, 500 or 1150° F.
5. Transversely bead-welding on both sides with E6020 electrodes at 175 amp. and 10 in. per minute followed by heating to 75 or 1150° F. (A-201 steel only).

The longitudinal bead-welds were three inches in length and were deposited before machining the throat. The transverse bead-welds were deposited on an 8 × 18-in. plate before cutting it into test specimens.

Tests at 500° F—The tests at 500° F. were run on A-201 steel only; the as-rolled steel received the following treatments before testing.

1. Heating to 75 or 1150° F.
2. 10% tensile straining parallel to the rolling direction, followed by heating to 75 or 1150° F.
3. Longitudinally bead-welding on both sides with E6020 electrodes at 175 amperes and 10 in. per minute, followed by heating to 75 or 1150° F.

NOTE—All heat treatments were conducted with a holding time of one hour.

Special Tests

In addition to the program described above, a number of tests were conducted on A-201 steel to investigate (1) the origin of cracking in welded specimens, and (2) the effects of low temperature cooling rates following welding on the resistance to repeated loading.

The technique for determining initial cracking in the specimens consisted of polishing the flat throat section, etching it very lightly, and scanning the area with a microscope at 50 diameters at frequent intervals during testing.

The study of low-temperature cooling rates involved testing at room temperature after the following treatments.

1. Welding with E6020 electrodes at 175 amp. and 10 in. per minute.
2. Heating to 200° F., welding with E6020 electrodes at 175 amp. and 10 in. per minute.
3. Welding with E6020 electrodes at 175 amp. and 10 in. per minute, followed 10 sec. after welding by heating at 200° F. for 1 hour.
4. Heating to 400° F., welding E6020 electrodes at 175 amp. and 10 in. per minute.
5. Welding with E6020 electrodes at 175 amp. and 10 in. per minute, followed 10 sec. after welding by heating at 400° F. for 1 hour.
6. Welding with E6020 electrodes at 210 amp. and 10 in. per minute.

Straining was carried out in reverse bending for these special tests at one level of strain, 0.5% in each direction.

EXPERIMENTAL RESULTS

Room Temperature Tests

The cycles to fracture as a function of strain level are shown in a series of bar graphs in Figs. 11 to 16. The cycle data are plotted on a logarithmic scale because of the range of variation. For this reason, the differences developed among the test variables appear compressed at high cycle levels.

Tests at 500° F.

The data obtained for the tests at 500° F. are presented in the bar graph of Fig. 17. Note again the semi-logarithmic scale.

Special Tests

Photographs of the worked surfaces of polished specimens comprise Figs. 18 and 19.

The data on low temperature cooling are shown in the bar graph of Fig. 20. A linear scale for the cycles to failure was satisfactory in this case, because only one strain level was involved.

DISCUSSION OF THE RESULTS

Tests at Room Temperature

The factors studied in this series of tests were (1)

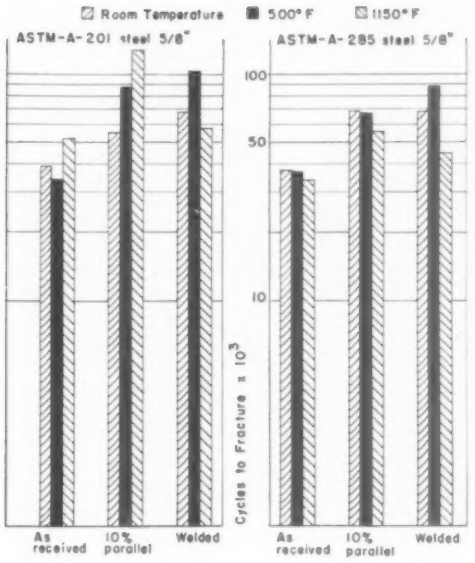

Fig. 11 (left) Room temperature repeated load tests above yield strain. Strain level: 0.15%

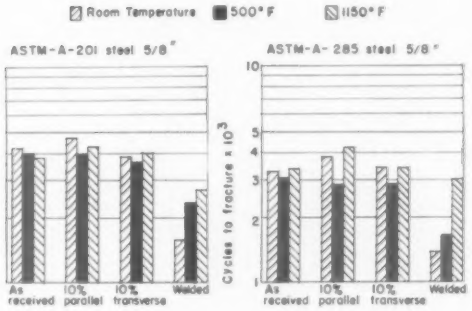

Fig. 14 Room temperature repeated load tests above yield strain. Strain level: 1.0%

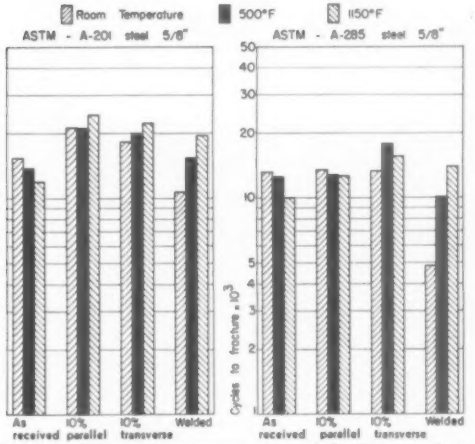

Fig. 12 Room temperature repeated load tests above yield strain. Strain level: 0.4%

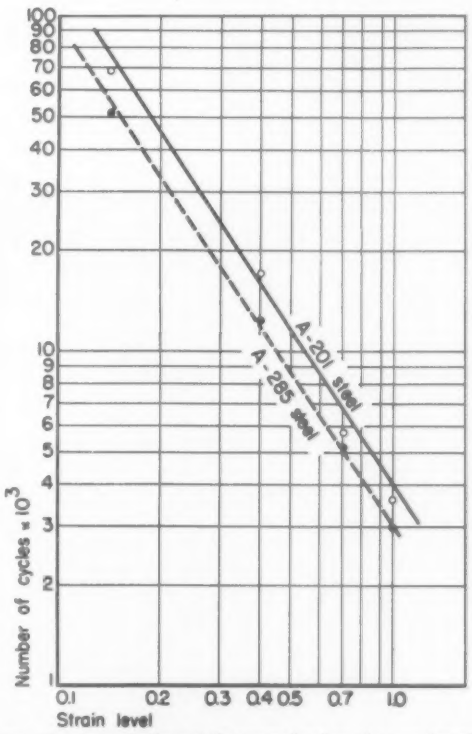

Fig. 15 General effect of the strain level on the number of cycles to failure under repeated load. (Averages of all conditions from Figs. 11–14)

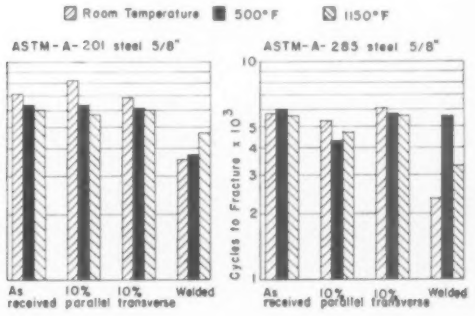

Fig. 13 (left) Room temperature repeated load tests above yield strain. Strain level: 0.70%

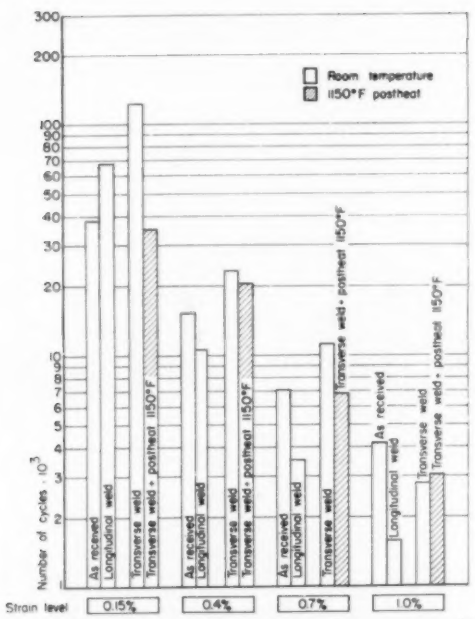

Fig. 16 Comparison of longitudinal and transverse weld beads

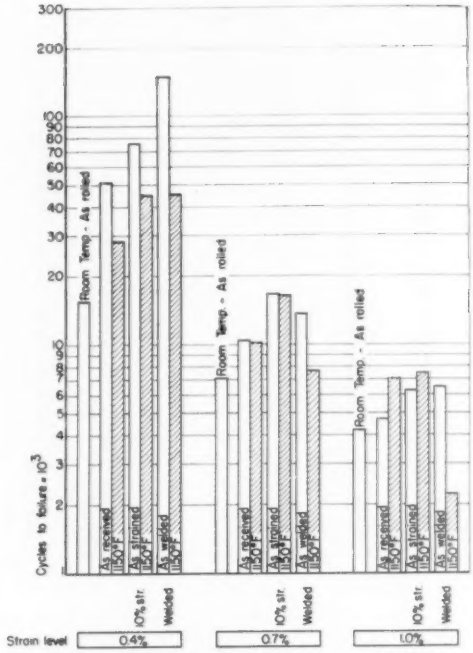

Fig. 17 Repeated load tests conducted at 500° F.

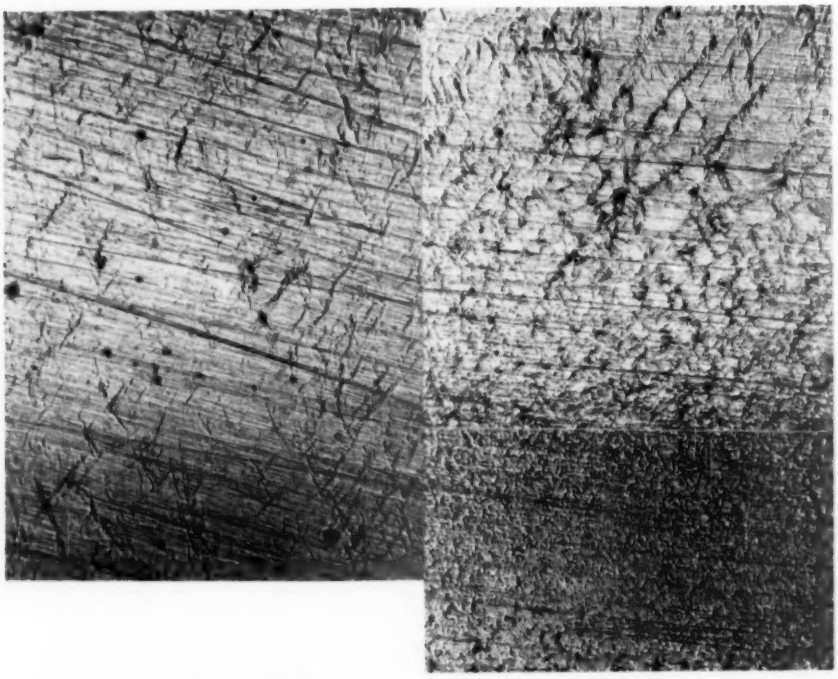

Fig. 18 Slip band formation in weld metal and heated zone of base plate. × 50

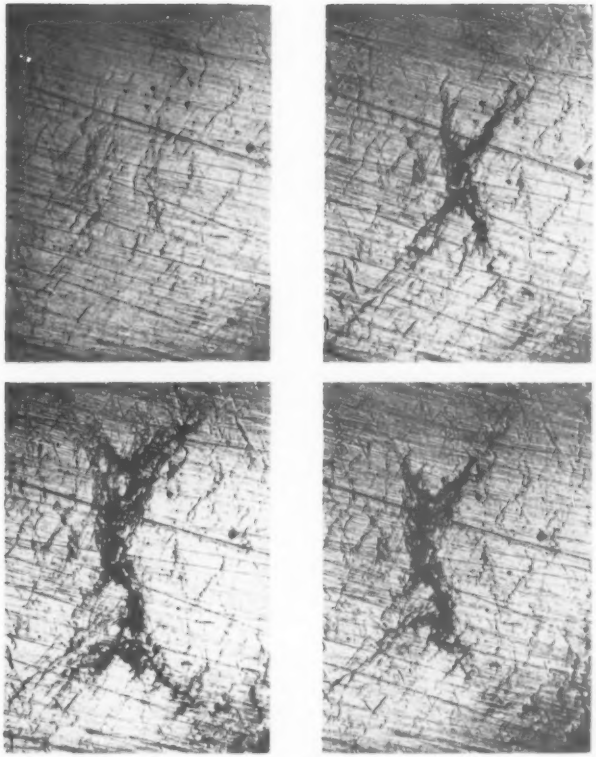

Fig. 19 Progression of a crack from slip bands in the weld metal. ×35

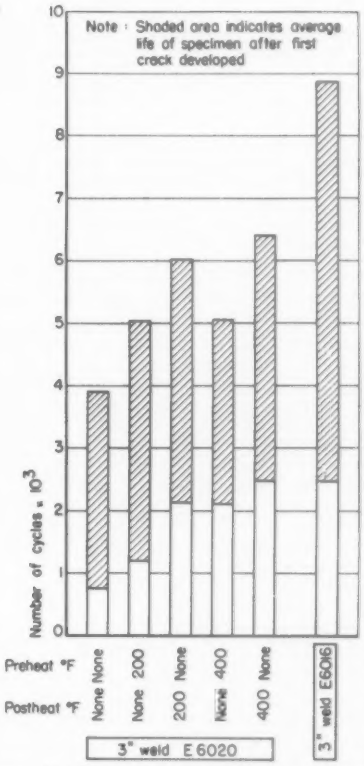

Fig. 20 Effect of low temperature cooling rate on repeated load resistance

steel composition, (2) prestraining, (3) welding and (4) postheating after prestraining or welding. From an examination of Figs. 11 to 15, the following observations can be made:

The A-201 steel averaged 20 to 25% higher in cycles to failure than the A-285 at all strain levels except the lowest, 0.15%, where the two steels behaved virtually alike. These differences were present in the as-rolled, in the prestrained, and in the welded tests, with only one or two exceptions.

Prestraining had no effect on tests at higher strain levels. At 0.15% strain, however, failure was delayed noticeably by prestraining. The direction of prestraining was not significant. The work-hardening effect of prestraining raises the yield and tensile strengths, and it thereby possibly increases the fraction of the deformation which is elastic, at the same time reducing the fraction of plastic deformation occurring in each cycle. At a low-strain level, this elastic fraction becomes appreciable and can be expected to delay failure. At high strain levels the elastic portion remains too small to be important.

Longitudinal welds reduced the cycles to failure as much as 50% at high strain levels. Only at 0.15% strain was there an increase in cycles obtained from welding. As will be shown later, the cracks resulting in failure originated in the weld metal, indicating that the fused metal possessed lower ductility than the base plate. At the low imposed strain level, the high yield strength of the weld acts to delay failure just as in the case of prestrained specimens.

As shown in Fig. 16, the specimens containing transverse weld-beads were little affected by welding. Failure occurred in either weld metal or base metal at random. The higher yield strength of the weld metal can be expected to force deformation into the adjacent base metal.

Postheating produced some puzzling effects. The treatment at 500° F. had little effect on prestrained material, but it provided unexpected improvement in most of the welded samples. Treatment at 1150° F. was especially beneficial to the welded specimens tested at the highest strain level. Treatment of the prestrained material at 1150° F. was mostly without effect, even at low strain levels where the loss in yield strength due to heating might be expected to lower the cycles to failure.

Tests at 500° F.

The tests at 500° F. are distinguished only by a gen-

eral tendency to be higher in cycles to failure than the tests at room temperature, especially at low-test strain levels. There is no tendency for strain-aging to lower the performance, despite the fact that 500° F. is within the blue-brittle range.

Origin of Cracking

Microscopic examination of the polished surfaces of specimens at frequent intervals during testing revealed that the first phenomenon visible was the formation of numerous slip-bands at roughly 45° to the direction of bending. As shown in Fig. 18, these bands were more numerous and marked in the weld metal than in the base plate. As testing continued some of the slipbands in the weld metal broadened and lengthened progressively until they became small cracks. This action is shown by the series of photographs in Fig. 19, in which the growing crack is indicated. Note the forked ends of the crack which seem to maintain the 45° orientation of the slip-bands. As the crack grows larger it can be seen to open and close, or "breath," during cycling.

The tendency of the weld metal crack is to halt momentarily at the fusion line before propagating into the base plate. In some cases, the cracking proceeds by a merging to concurrently formed smaller cracks. Frequently there are numerous small cracks to either side of the main crack which are arrested when the load on them is relieved by the "breathing" of the large crack.

This brief study has shown that cracks apparently originate from slip-bands, and in the welded specimens, tend to initiate in the weld metal rather than in the base plate of the steels that have been tested.

Effects of Low Temperature Cooling Rates

The work of Bland and of Flanigan has indicated that the rate of cooling from 400° F. to room temperature after welding with electrodes with coatings high in hydrogen content may influence the final properties of the weld. If the cooling rate is rapid, retained hydrogen may cause microfissures in the weld metal, the notch effect of which will lower the mechanical properties of the metal.

In Fig. 20, the results of a short study on this subject are summarized. Preheating or immediate postheating were used to retard the low temperature cooling. The level of the cycles to failure is raised about 20% by preheating and 50% by postheating. The specimens welded with E6016 show some 100% improvement over the E6020 welds. From this it appears that there is a deleterious effect of the low temperature cooling rate when welding is performed with electrodes which supply a large volume of hydrogen-bearing gas to the arc atmosphere.

SUMMARY

The results of the investigation can be summarized as follows:

1. A specimen and machine design has been developed to test the resistance of steel to repeated loads in the plastic range.
2. To produce failure in the range of 1000–100,000 cycles, such as may be experienced in pressure vessels, plastic strains between the yield strain and 1% were required.
3. On the average the A-201 steel performed some 20% better than the A-285 steel.
4. Cold work affected the cycles to failure only at low test strain levels, where it raised the level of resistance.
5. At all test strain levels over 0.15% longitudinal weld-beads lowered resistance to repeated loading.
6. Initial cracking originated from slip-bands that formed at 45° to the axis of bending. In welded specimens with longitudinal beads, cracking initiated in the weld metal. In transverse bead-welded specimens cracking occurred indiscriminately in weld or base metal.
7. Postheating at 1150° F. did not improve cold worked (10% prestrain) specimens, but raised the cycles to failure of welded samples, especially at higher test strain levels.
8. Reducing the low temperature cooling rate after welding with E6020 electrodes was shown to be beneficial. Welds with low-hydrogen electrodes outperformed those of E6020 electrodes by about 100%.

ACKNOWLEDGMENTS

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Surface Tension and the Joining of Metals

Requirements of surface tension for the design of brazing alloys are pointed out and discussed

by E. R. Funk and H. Udin

Abstract

The principles of capillarity and wetting which are of particular concern to the field of joining are outlined in this paper. Since capillarity and wetting are manifestations of surface tension, the methods at hand for the determination of the surface tensions and interfacial tensions met with in joining are reviewed. The requirements in terms of surface tension for the design of brazing alloys are pointed out and some industrially significant systems are discussed in this light

INTRODUCTION

IT IS not surprising that welding engineers should have a special interest in surface properties and related phenomena since the aim of the joining processes is the obliteration of two surfaces to form a continuum. The interest in surface properties is not, however, confined to those in the joining field. Solid state physicists, chemical engineers investigating catalysis, mechanical engineers studying lubrication as well as metallurgists concerned with the sintering of metal powder compacts have all recognized the importance of surface phenomena in metals. Workers in each of these fields have made contributions toward our present knowledge of surfaces. It is the purpose of this paper to assemble those concepts which are of particular concern to the field of joining.

Some qualitative principles of capillarity as applied to joining have been long recognized by welding engineers. Thus it is well known that the shape and contour of a weld bead is related to the viscosity of the slag as well as its surface tension. The spreading power of a flux is also related to its surface tension and the surface tension of the solid metal.

It also has been recognized that brazing, for example, is correlative in some way to capillary forces and surface tension. Indeed, the handbooks urge the use of metals of low surface tension for brazing alloys. We have shown in a companion paper that this statement must be modified in the light of our present knowledge.

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In the brazing process metallic parts are joined by a non-ferrous filler metal or alloy whose melting point is higher than 450° C. but lower than the parts joined. In this industrially important process steel, copper or nickel may be joined by brazing alloys which contain copper, silver, zinc and other metals. Before the filler metal is added a flux, usually a metal halide or borax, is applied. This flux prepares the surface of the metal by dissolving the metal oxides, and protects it from further oxidation. The flux as well as the molten brazing alloy spreads over the surface. The force responsible for this spreading is surface tension. It is this same force which holds molten metal in a vertical or inverted joint during welding.

To visualize surface tension let us consider the environments of atoms in a liquid or solid body. An atom or ion in the interior of a solid or liquid is surrounded, more or less symmetrically, by similar particles. However, when it resides in the surface this symmetry is lost. If we think of the particle as being held to its neighbor by elastic bands, some of these bonds will be distorted or completely unattached. This excess of energy of these bonds makes the surface a region of high energy compared to the interior, and if the body is free to do so, it minimizes its energy content by assuming a spherical shape, the shape possessing the least surface area per volume. In determining the numerical values of this energy we must realize that in any real system the surface is actually a boundary between two phases. Even if one phase is a gas, its properties must be considered. When the gas is the vapor of the solid or liquid in question then we shall speak of the excess energy at the boundary as surface energy or its numerical equivalent, surface tension. All other cases will be examples of interfacial energy or tension.

CAPILLARITY IN BRAZING

It is easy to picture the brazing alloy being carried between the surfaces of a joint by a capillary force. This capillary force exists at a liquid/solid interface due to the manner in which a liquid and a solid meet. Whenever a liquid and a solid meet there is a definite angular relationship established between them. The

angle between the solid and the tangent to the liquid at the point of juncture has been called the contact angle and is denoted by θ. The magnitude of θ is determined by the surface tensions of the solid and liquid phases and the interfacial tension between these phases. It is a constant for any given system, but it may vary from 0 to 180° depending on the liquid-solid system chosen. When a drop of liquid is placed on a solid it spreads until the equilibrium angle θ is established.

The fact that the liquid does meet the solid at an angle θ means that in a confined space a meniscus will result. In small tubes this meniscus is very nearly hemispherical while in large tubes a flatter, less curved surface is found. Similarly, between closely spaced flats the meniscus is semi-cylindrical, while between widely spaced flats the meniscus shape is more complex. Since all brazed joints are between plates only a small distance apart we can consider that the resulting meniscus is semi-circular in cross section.

The fact that the surface of the liquid is curved is of primary importance. It leads directly to the fact that the pressure under the meniscus is less than the pressure surrounding the system. A classic equation of Laplace expresses this pressure difference as

$$\Delta P = \gamma \left(\frac{1}{R_M} \right) \qquad (1)$$

where γ is the surface tension of the liquid-gas interface and R_M is the mean radius of curvature.

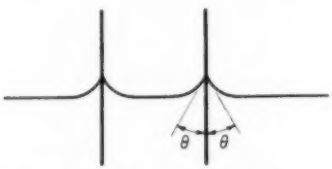

Fig. 1 Formation of the contact angle when two plates are thrust into a liquid

To understand this more clearly let us perform a simple experiment. Take two clean plates and thrust them beneath the surface of a liquid as in Fig. 1. Immediately the liquid and the solid surface energies cause the contact angle θ to develop. With this comes the expected meniscus, a full meniscus between the plates and a half meniscus on the extreme sides of the plate. The pressure under the surface, some distance away from the plates, is atmospheric while the pressure under the curved surface is less by an amount ΔP. Such an unnatural condition cannot be expected to remain unchanged. The low pressure area (under the meniscus) commences to move upward until the weight of the column drawn upward just compensates for ΔP. When this condition of equilibrium is reached, movement ceases and we can then write that

$$\Delta P = \rho g h \qquad (2)$$

ρ is the density of the liquid, g is the acceleration due to gravity. Now the pressure in the confined space at the level of the external liquid is just equal to the pressure in the internal liquid. See Fig. 2. The weight of the column of the liquid has just increased the pressure in the confined space at the ambient level by ΔP or $\rho g h$.

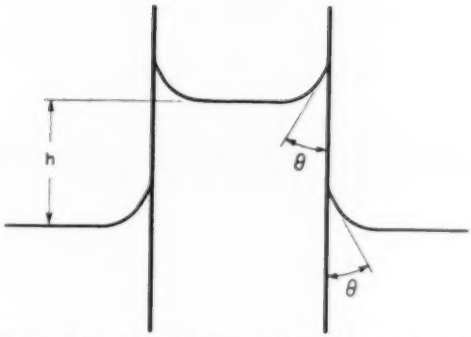

Fig. 2 Rise of liquid between plates as a result of the curvature of the meniscus

The capillary rise, h, may be related to the surface tension of the liquid by Equation 1. Thus,

$$\rho g h = \gamma \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \qquad (3)$$

where R_1 and R_2 are the radii of curvature in two planes at right angles.

We will restrict ourselves in this paper to liquids rising between infinite flat plates. In such a case the mean radius of curvature becomes $D/(2 \cos \theta)$ since R_1 is infinity while R_2 is $(2 \cos \theta)/D$. D is the distance between the plates and θ is the contact angle. From Equation 3 we can obtain

$$\gamma = \frac{D \rho g h}{2 \cos \theta} \qquad (4)$$

This familiar equation is often used to determine the surface tension of liquids by measuring the amount of capillary rise between plates. In these determinations the contact angle θ is usually measured in an auxiliary experiment.

WETTABILITY

The contact angle θ is related directly to the *wetting power* of a liquid. How the contact angle is a measure of the wetting power may be seen by taking one of the flat plates of our previously described experiment and allowing a drop of liquid to come to rest upon it. As before, an angle—the contact angle θ—is soon established between the liquid and the solid. This droplet of liquid which partly wets a solid substrate will take a shape which minimizes the surface energy of the system. On the line of contact among the gas, liquid, and solid phases the surface forces are in equilibrium parallel to the solid surface, as in Fig. 3. Then an equation of balance in the horizontal direction can be written

$$\gamma_{SV} = \gamma_{LS} + \gamma_{LV} \cos \theta \qquad (5)$$

where γ_{SV} = surface tension of solid/vapor, γ_{LS} = liquid/

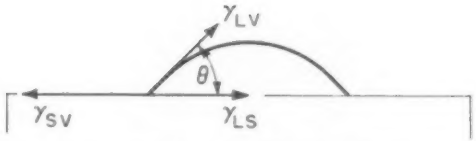

Fig. 3 Vector diagram of the surface tension forces of a liquid droplet

solid interfacial tension, γ_{LV} = surface tension liquid/vapor.

This is the fundamental equation of wetting. Several specific cases are illustrated in Fig. 4 which shows the relationship between the contact angle and the wetting power, e.g., of a liquid flux or slag on a solid metal. In each case a free plane surface and a capillary column are illustrated.

4a is the very common case of complete wettability. Examples of this are lubricating oil on metals, water on most clean metals, water on fabric. Borax on metals and many liquid metals on solid metals are also familiar cases of complete wettability. The requirement is clearly that θ shall be zero, so that

$$\gamma_{SV} = \gamma_{LS} + \gamma_{LV} \qquad (6)^*$$

The rate of filling of a capillary when complete wetting obtains is considered in a related paper. *4c, d, e* are rare for liquid flux or slag on solid metal, *d* and *e* may well be non-existent for this case. This is because metals in general have high surface tension compared to low-melting inorganic compounds. For the same reason, *c, d* and particularly *e* are common for the converse case, that of liquid metal on solid slag or metal oxide. Thus, as is well known, the principal function of a welding flux is to dissolve oxide coatings so as to permit the weld metal to wet the parent metal.

Bailey and Watkins[1] were interested in checking the equations of wetting in a system of particular interest in the joining of metals, the lead-copper system. They detected an apparent anomaly in Equation 5 arising from the following experimental observations:

1. The surface tension of solid copper was found by Udin[2] to be about 1700 dynes per centimeter.

2. The surface tension of liquid lead is about 450 dynes per centimeter.[3]

3. C. S. Smith,[4] from measurements of dihedral angles in the system copper/lead, found that the lead/copper interfacial energy is 0.6 times the grain boundary energy of copper.

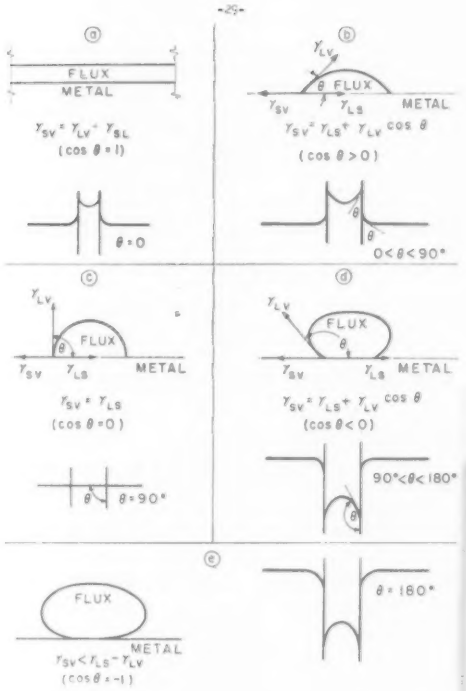

Fig. 4 Various capillary and wetting conditions found with variation of contact angle from 0 to 180°

4. Liquid lead does not wet solid copper perfectly.

These facts, in conjunction with Equation 3, would seem to require that the grain boundary energy of copper be at least 2000 ergs. per centimeter², which was considered highly unlikely. To investigate this situation, Bailey and Watkins determined the quantity $\gamma_{SV} - \gamma_{LS}$ for the system copper/lead at 900° by measuring the angle θ in an experiment conforming to Fig. 3. They then measured the thermally etched groove angle at the intersection of a grain boundary with a copper surface exposed to lead vapor (Fig. 5) and compared this angle with the dihedral angles measured by C. S. Smith. From Figs. 5 and 6 it is evident that

$$\gamma_b = 2\gamma_{SV} \cos\frac{\psi}{2} = 2\gamma_{LS} \cos\frac{\omega}{2} \qquad (7)$$

$$\frac{\gamma_{SV}}{\gamma_{LS}} = \frac{\cos\frac{\omega}{2}}{\cos\frac{\psi}{2}} \qquad (8)$$

Having numerical values for the difference $\gamma_{SV} - \gamma_{LS}$ and for the ratio γ_{SV}/γ_{LS}, the individual tensions are determined. The apparent anomaly disappeared when it turned out that the interfacial tension solid copper/lead vapor is only 800 dynes per centimeter. Thus, the presence of the lead vapor reduced the surface

* This equation is usually written

$$\gamma_{SV} > \gamma_{LV} + \gamma_{LS}$$

However, Harkins and Loeser[12] have shown that the inequality applies only when the solid is not in equilibrium with the vapor phase. For the equilibrium system, where the liquid and solid are mutually saturated, and the vapor is in equilibrium with both phases, the surface energy of the solid phase must equal the sum of the energies of the liquid-vapor and the liquid-solid interfaces. To completely define the system, Harkins writes Equation 6 in the form

$$\gamma_{SV^\circ} = \gamma_{LV^\circ} + \gamma_{LS}$$

where V° represents saturated vapor.

The reason for the equality is not difficult to see. If a piece of clean glass, for example, is equilibrated with moist air at 100% relative humidity, enough moisture is adsorbed so that two distinct interfaces, glass/water and water/air, already exist. Physically transferring more water to the surface will thicken the moisture layer, but will not alter the nature or energy of the interfaces. Thus in a sense Equation 6 is an identity rather than an equality.

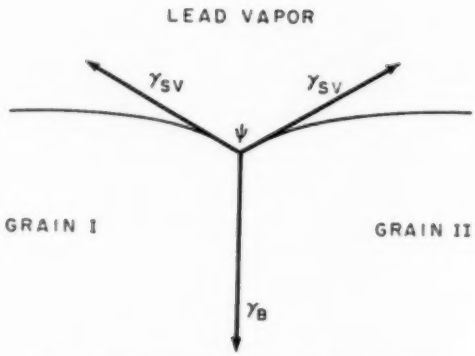

Fig. 5 Surface tension forces at a grain boundary

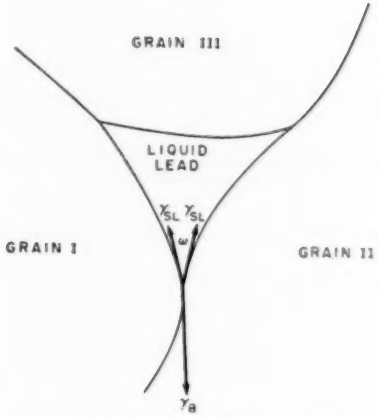

Fig. 6 Interfacial tension forces at a grain corner

tension of solid copper measured in a vacuum by 900 dynes per centimeter. The value of the solid copper/liquid lead turns out to be 360 dynes per centimeter. It was found by the present authors by techniques to be discussed in the next section that oxygen reduces the surface tension of silver to such an extent that in air the "surface tension" of silver is only one-third of its value in helium.

SURFACE TENSION

It is clear from the foregoing discussion that the success or failure of a brazing operation is determined uniquely by the interfacial tensions acting in the joint. Actual measurement of these interfacial tensions is complicated by the fact already pointed out that the presence of a foreign vapor phase may change the surface tension values markedly from these obtained against a vacuum. Nevertheless, techniques are available for the measurement of the pertinent surface tensions and interfacial tensions for all systems of practical significance in brazing. Thus, the surface tension of a liquid brazing alloy may be determined by the well-known sessile drop method,[4] or by the bubble pressure method,[5] or more simply, by the capillary rise method employing Equation 3. The interfacial tension between a liquid phase and a solid phase has been treated by C. S. Smith,[4] Sears[5] and others.[1, 6] The surface tension of a solid metal in a foreign vapor has been treated for one case by F. Buttner, E. R. Funk and H. Udin[7] by a method previously developed by H. Udin, A. Shaler and J. Wulff.[8]

In the experimental procedure of this latter group the contractile forces resulting from the surface tension in fine wires were opposed by a dead load suspended from the wire. By using several wires each differently weighted, the resulting creep strain in these wires at high temperatures could be followed as a function of the applied load. At low loads the greater contractile force of surface tension caused the wire to shrink, while at higher applied loads the surface tension was overbalanced and the wires elongated. From the strain versus load plot, the value of the load which just balanced the surface tension was found. This balancing load is a measure of the surface tension as shown in the following paragraphs.

Consider a wire of length l and radius r made up of n + 1 grains. Each grain has a cross section equal to that of the wire, with boundaries essentially perpendicular to the wire axis. A weight w, just sufficient to balance the shrinkage force of surface tension, is suspended from one end of the wire. Taking the x axis along the wire, with tension positive, we find, for the axial stress

$$\sigma_x = \frac{\omega - 2\pi r\gamma}{\pi r^2} \qquad (9)$$

where γ is the surface tension of the wire. The stresses perpendicular to the wire, σ_y and σ_z, are equal and derive from two surface tension forces, the circumferential force of the surface tension and the line forces exerted by each grain boundary. These forces resolve into

$$\sigma_y = \sigma_z = -\left(\frac{\gamma}{r} + \frac{n}{l}\gamma^*\right) \qquad (10)$$

where γ^* is the grain boundary tension.

If this wire is heated to within about 100° of its melting point it will creep at any stress not equal to zero, and the strain rate at any time will bear some power relationship to the stress. This permits us to say that

$$\mathbf{E}_x(\tau) \sim \left[\sigma_x - \frac{1}{2}(\sigma_y + \sigma_z)\right]^n \qquad (11)$$

where $\mathbf{E}_x$ is the strain rate in the axial direction, and may be a function of time also. At balance, the strain rate equals zero, and the terms within the brackets in Equation 11 must also equal zero. Thus, from Equations 9 and 10

$$\omega = \pi r\gamma - \frac{n}{l}\pi r^2\gamma^* \qquad (12)$$

From this equation one can determine surface tension

from a single experiment if the grain boundary tension is known, or if the ratio of grain boundary tension to surface tension is known. This ratio has been measured by Greenough[9] and found to be approximately one-third for silver. The ratio appears to be nearly the same for copper and gold. The experimental techniques used for copper[8, 2] and silver[10] and gold[11] have been reported elsewhere. The solid surface tensions are

γ copper = 1800 dynes per centimeter
γ silver = 1140 dynes per centimeter
γ gold = 1370 dynes per centimeter

at temperatures within 100° C. of the melting point.

Methods are at hand for the determination of all the unknowns in the wettability equation for most systems met in joining. Thus, the solid/vapor surface tension may be determined by the method just described. The liquid/vapor surface tension can be determined in various ways from the manifestations of the capillary pressure. The interfacial solid/liquid tension requires more subtle methods. The techniques of Bailey and Watkins[1] and of Sears[5] apply only where complete wetting does not occur, and these systems are rarely met in joining. Where complete wetting occurs the techniques of Van Vlack[6] can often be applied. Essentially, then there are two approaches to such systems. Since

$$\gamma_{SV} = \gamma_{LV} + \gamma_{LS} \qquad (13)$$

one can determine γ_{LV} by capillarity. Then γ_{SV} can be measured by the wire technique, or γ_{LS} by the Van Vlack method. In a few systems, liquid copper/solid iron for example, both approaches are applicable, and a cross-check can be obtained.

APPLICATIONS TO WELDING AND BRAZING

The design of a brazing alloy to be used with a specific solid or group of solids will require, among other things, that the contact angle be nearly zero and the relationship which this requires is that

$$\gamma_{SV} \approx \gamma_{LS} + \gamma_{LV} \qquad (14)$$

the previous sections have outlined the available methods and experimental precautions for the determination of each of these figures. The unexpectedly large effect of small amounts of oxygen on the surface tension of solid silver suggest that the change of the variables in the Equation 14 with atmosphere might lead to useful results. Thus, in controlled atmosphere furnace brazing if the presence of a certain gaseous compound lowered γ_{LV} more proportionately than it does γ_{SV}, the chances of complete wetting are increased in this system. No experiments of this nature are known so that there is no way of predicting the results.

In most joining processes a flux is present. In principle this case is no different from those already discussed. For example, Fig. 7 shows a hypothetical case where the flux wets the solid metal, but the liquid metal under flux does not. The equation of balance is identical to Equation 5 except that γ_{LF} and γ_{SF}

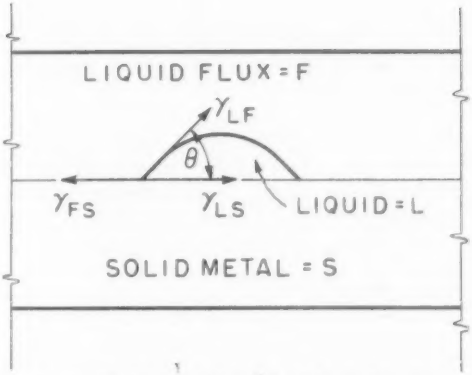

Fig. 7 The flux-liquid metal-solid metal system

replace γ_{LV} and γ_{SV} respectively. γ_{LF} can be determined by measurement of differential capillary rise.[6] The wire technique is not practical for γ_{SF}, but experiments similar to those of Van Vlack[6] and of Sears[5] can be used. Again the composition of the gas phase may influence the actual values of all three parameters.

When all three phases mutually wet, three layers will result. The liquid metal tunnels under the flux, not under the influence of gravity, but because the sum $\gamma_{SL} + \gamma_{LF} + \gamma_{FV}$ is less than $\gamma_{SF} + \gamma_{LF} + \gamma_{LV}$. Since γ_{LF} appears in both sums we can write

$$\gamma_{SF} + \gamma_{LV} > \gamma_{SL} + \gamma_{FV} \qquad (15)$$

Of these four parameters, the one most likely responsible for the inequality is γ_{FV}. Most measurements of surface tension of liquid fluxes have led to values much lower than those for liquid metals. On the other hand, in the one experiment (that of Van Vlack[6]) where γ_{SF} and γ_{SL} were measured, the two solid-liquid energies were nearly equal.

As we have seen, the inter-relating effects of one phase upon another vastly complicate the procedure for a quantitative study of wettability in joining processes. For such a study the surface tensions of the alloy and joined material must be investigated individually under the flux and atmosphere conditions met with an actual practice. We have only begun to collect this large body of data. A study of the surface tension of liquid flux in the presence of the actual brazing atmosphere is essential. Moreover, the surface tension of liquid alloys as well as the solid materials joined should be traced as the various fluxes and atmospheres of joining are applied. With this new body of knowledge available it may well be possible to design fluxes, brazing alloys and brazing atmospheres from the first principles of wetting.

Many similar problems are met with in fusion welding. Here we have even less background of quantitative information. We know that welding slags are "wetter" than steel-making slags. However, we have no information whatsoever on the actual interfacial energy relationship. Information gathered in this field should

lead to a better understanding of slag-metal reactions as welding. Derge,[12] for example, has already found that the use of "wet" open hearth slags speeds up steel-making reaction rates.

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APPENDIX

In the main body of this paper we have only been concerned with cases in which thermodynamic equilibrium between the various phases obtains. For example, the copper-iron system has been discussed as an equilibrium case. This is justifiable because the relatively low mutual solubility and the high temperatures of brazing allow the two phases to approach surface equilibrium very rapidly. But it is readily apparent that while there are certain systems which are inherently equilibrium systems other systems are not inherently equilibrium cases. Many of the commercially important systems turn out to be non-equilibrium.

Easy-Flo brazing alloy on steel is a non-equilibrium system. Easy-Flo is a proprietary alloy of 50% silver, 15.5% copper, 16.5% zinc, 18% cadmium. Examination of the appropriate iron-constituent phase diagrams shows that 10% by weight zinc is soluble in solid iron at 400° C. The remaining constituents of Easy-Flo are not soluble to any extent in solid iron. The time of brazing is hardly long enough for the iron to reach saturation with zinc so that this system is truly non-equilibrium. The suspected cadmium-iron and known zinc-iron intermetallic compounds may or may not form substantially on the surface of the iron. In any case the very fact that such compounds exist precludes the possibility of thermodynamic equilibrium.

The common lead-tin solders on copper probably do not reach equilibrium. Tin is highly soluble in copper and copper is probably soluble in liquid solder. Here again the relatively low temperatures and brief brazing times legislate against true equilibrium.

A system which is potentially equilibrium is the soldering of iron with lead-silver alloys. These alloys were used experimentally during the war. The very low solubility of both lead and silver in iron means that at the soldering temperature complete mutual saturation may occur in a reasonably short time.

The time to achieve mutual solubility and thus equilibrium results in some interesting phenomena. Bailey and Watkins[16] have examined the wetting characteristics of many liquid metal-solid metal combinations. They discovered that tin solders "dewet" on copper. Thus, when the copper surface was flooded with solder, complete wetting occurred, but the liquid quickly collapsed into a collection of lens-shaped droplets. Actually solder should spread completely over a clean copper surface, and then as adsorption of lead and tin upon the copper occurs and thus equilibrium is reached, the solder draws back into a lens. This phenomenon occurs spectacularly with certain organic liquids on water.[17] It happens, of course, because the adsorbed metal reduces the γ_{SV} from an originally high value to an appreciably lower value so that the minimum energy of the system demands that the solid-vapor surface be exposed.

Another very interesting non-equilibrium phenomenon not as yet well understood is secondary spreading. When a droplet of liquid metal is placed on a solid, a fairly definite contact angle is established. After a short period, the droplet spreads further and a second much smaller contact angle is established. This secondary spreading seems to be a property of commercially acceptable soft solders. This is probably due to a decrease of either the liquid-solid or the liquid-vapor vector. See Fig. 3.

The Effect of Quench-Aging on the Notch Sensitivity of Steel

Quench-aging is sometimes responsible for the brittle zone adjacent to welds in semi-killed mild steel and in such cases may be improved by a low temperature post-heat treatment

by J. R. Low, Jr.

Abstract

Charpy impact test specimens of a semi-killed 1020 steel were quenched from 690° C. and aged at room temperature for periods up to three years. During this period the transition temperature increased from −40° C. to 0° C. Over-aging at 350° C., either immediately following quenching or after three years aging, lowers the transition temperature to −15° C. It is suggested that quench-aging is responsible for the commonly observed brittle zone adjacent to welds in this grade of steel and that a low-temperature post-heat treatment similar to that used for over-aging should improve the low temperature ductility of welded structures made of this and similar grades of steel.

It is also shown that a decrease in the cooling rate from 690° C. raises the transition temperature; this effect is believed to account for the fact that as-rolled plates show an increase in transition temperature as the thickness increases.

THE fact that strain-aging may raise the notched bar impact transition temperature of mild steel is now well recognized and the phenomenon has been widely studied. The fact that quench-aging[1, 2, 4, 5] also occurs in this class of steels and may also raise the impact transition temperature has not received as much attention as a possible factor in the brittle failure of welded structures. The thermal cycle required to initiate quench-aging, i.e., a short time of heating in the range 500 to 700° C. followed by rapid cooling, may well occur in the heat-affected zone immediately adjacent to a weld, particularly in heavy plates. That portion of the base metal which experiences such a thermal cycle can then be expected to decrease in ductility with time of aging at room temperature, ultimately leading to a brittle region having a much higher transition temperature than the unaffected base metal as the data to be presented will demonstrate. This brittle region may be partially eliminated by a short-time low-temperature post-heating in the neighborhood of 350° C.

Quench-aging effects may also be produced, but to a lesser degree, by slow cooling from the 500–700° C. temperature range. It is believed that the precipitation which occurs during such slow cooling is at least partially responsible for the generally observed effect of thickness on the impact transition temperature of as-rolled mild steel plates, i.e., that the heavier the plate the higher is the transition temperature.

EXPERIMENTAL PROCEDURES

The material used throughout this investigation was a semi-killed steel, in the form of $\frac{1}{2}$-in. hot-rolled plate of the following analysis: C, 0.17; Mn, 0.75; P, 0.017; S, 0.035; Si, 0.044.

Standard key-hole Charpy specimens were cut from the plate with their long axes parallel to the rolling direction and with their notch axes perpendicular to the plate surface. The specimens were prepared except for notching, were heat treated, and then notched. Those specimens designated "as-quenched" were notched and tested within five hours of quenching. During this time they were kept at 0° C. except for the short time required to drill and slot the standard notch.

The quench-aging heat treatment consisted of heating for five minutes at 690° C. in a lead bath, water quenching, and then aging at room temperature (20–25° C.) for periods up to three years. The short time at the solution annealing temperature was felt to be adequate for saturation of the ferrite by carbon or nitrogen but not long enough to cause pearlite spheroidization or changes in ferrite grain size. No microscopic evidence could be found for any structural changes as a result of this solution anneal.

The impact testing procedure consisted of cooling or heating the specimens in an appropriate bath of dry ice and acetone, ice and water, or warm water and

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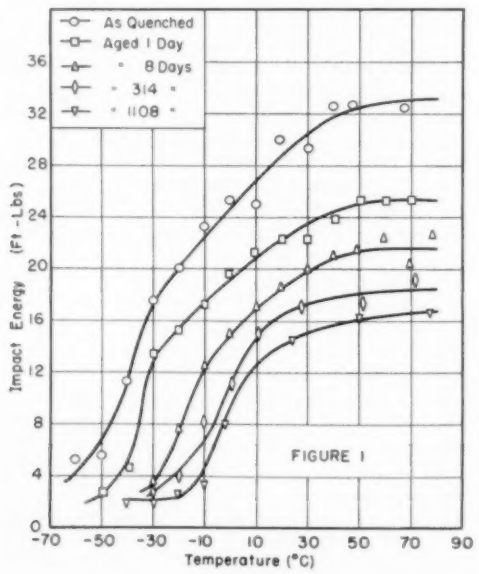
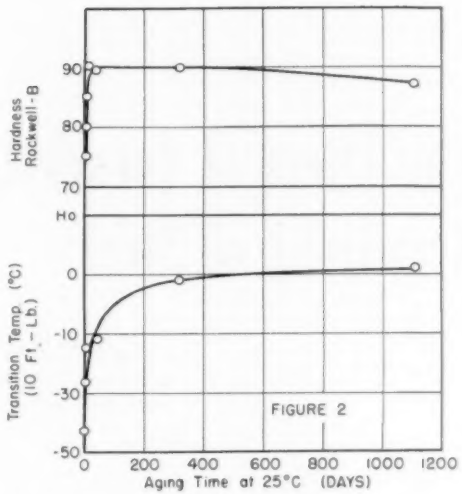
then breaking in a standard impact machine. Where the test required heating above room temperature the time in the bath was limited to a maximum of three minutes to minimize accelerated aging during heating for impact testing. A preliminary investigation showed that this time was sufficient to bring the center of the specimen to the bath temperature. As a check for accelerated aging during heating for impact testing, hardness measurements were made on undeformed portions of the Charpy test bars *after* they had been broken. In no case did the mean of the hardness values for the specimens broken above room temperature differ from that of those broken below room temperature by more than one-half of a Rockwell "B" number.

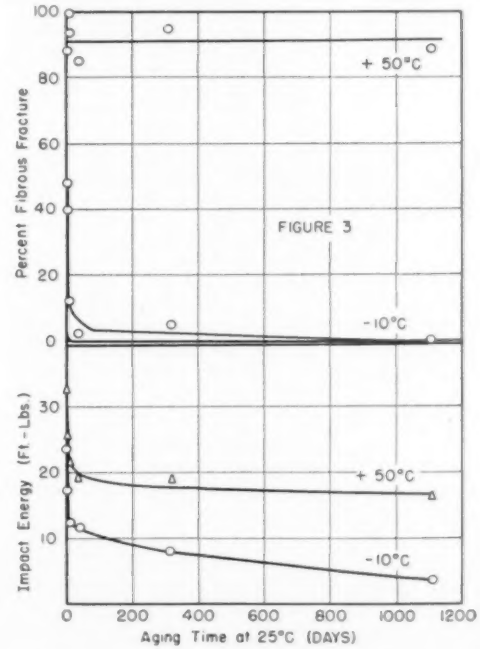
EFFECT OF QUENCH-AGING ON THE IMPACT TRANSITION TEMPERATURE

The impact energy versus temperature curves obtained for various room temperature aging times up to 1108 days (about three years) are shown in Fig. 1. Each of the experimental points shown is the mean of three test values; in only three cases did the energy values which were averaged differ by more than 4 ft.-lb. If the transition temperature is taken as the temperature at which the impact energy curve falls to 10 ft.-lb., Fig. 1 shows that the transition temperature has been raised from approximately −40° C. to 0° C. as a result of quench-aging. The rate at which the transition temperature shifts as a result of quench-aging is better illustrated in the lower section of Fig. 2 where this transition temperature is plotted against the time of room temperature aging. Here it is seen that a very rapid increase in transition





temperature occurs during the first ten days after quenching, followed by a slower rate of increase. However, even at the end of three years there is no indication that the transition temperature has begun to decrease due to overaging. In this same period, as shown in the upper part of Fig. 2, the hardness has reached a maximum and begun to decrease. A second result is that the level of energy absorbed above the transition temperature has been drastically lowered: from 34 ft.-lb. before aging to about 17 ft.-lb. after three years' aging.



Additional impact strength data, obtained at more closely spaced time intervals, together with the change in fracture appearance as a function of aging time at room temperature, are shown in Fig. 3. Here the impact strengths at $-10°$ C. and $+50°$ C. (both temperatures above the initial transition temperature), are plotted against aging time. At the longest aging time, the transition temperature, which was initially well below $-10°$ C. is now above this temperature. In addition, the energy absorbed above the transition temperature ($+50°$ C.) is still falling. As may be seen in the upper part of Fig. 3, this latter decrease in impact strength at high temperature is not accompanied by a change in fracture appearance, indicating that the decrease results from a change in the flow curve of the material and not from a change in the mode of fracture.

LOW-TEMPERATURE POST-HEATING TO AVOID QUENCH-AGING EMBRITTLEMENT

In so far as hardness changes are concerned, it is well known[2] that low and medium carbon steels may be "overaged," i.e., returned to their original hardness, in a few minutes at temperatures above 100° C. If it could be demonstrated that these materials will also overage rapidly with respect to the change in transition temperature, then a welding procedure which included a low-temperature post-heating of the heat-affected zone should completely eliminate the danger of progressive embrittlement due to quench-aging. Klingler and Ebert,[3] using an eccentrically loaded notched tensile specimen to compare notch ductility at various points in and adjacent to welds in steel plates, report a region of low ductility in the heat-affected zone. This they attribute to quench-aging, although they did not study the effect of aging time. In addition, they showed that post-heating at 1100° F. (593° C.) following welding would eliminate the region of lowered ductility in the heat-affected zone. The experimental results described below indicate that a considerably lower post-heating temperature might be used to bring about overaging in the brittle region without the risk of starting a quench-aging cycle in the region adjacent to the post-heated portion of the weldment.

Experiments to determine the optimum post-heating temperature were performed using changes in hardness for the preliminary exploration. Hardness specimens which had been quenched from 690° C. and aged three years at room temperature were heated to various temperatures above room temperature, held two minutes, and then water quenched.* This thermal cycle was chosen in an attempt to simulate a practicable post-heating cycle. The Rockwell "B" hardness values obtained for various reheating temperatures are shown in Fig. 4. The optimum temperature

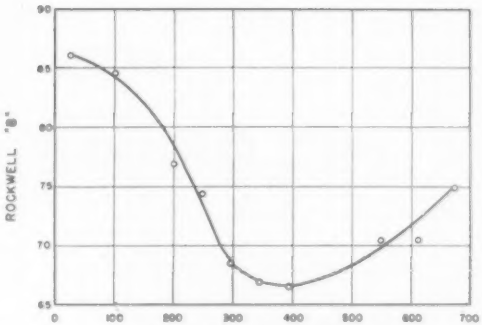


FIGURE 4

range for overaging (for this short time of heating) is seen to be between 350 and 400° C. Below this range, longer times of heating would be required and above it there is danger of starting another quench-aging cycle by the re-solution of carbon or nitrogen.

The effect of heating to 350° C. for five minutes and water quenching on the key-hole Charpy impact curve is shown in Fig. 5, where the curve for the overaged condition is compared with as-quenched and the as-quenched and aged conditions. The similarity of the two sets of data for the overaged condition, one for specimens overaged immediately following quenching, the other for specimens overaged after three years, indicates that the elapsed time between welding and post-heating would not be critical.

The results shown in Fig. 5 indicate that a low-temperature post-heat treatment in the neighborhood of 350° C. should do much to eliminate the region of minimum ductility commonly observed adjacent to welds in this class of structural steels and markedly

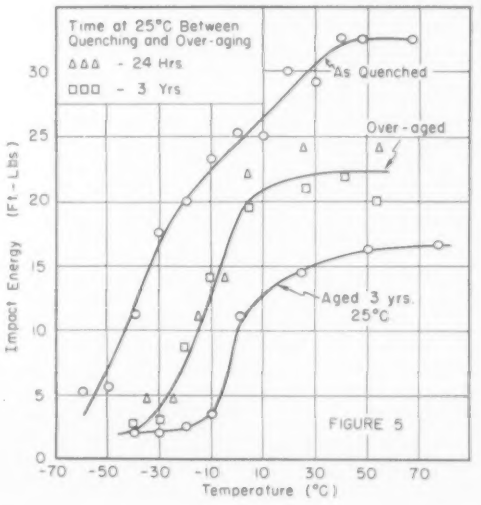
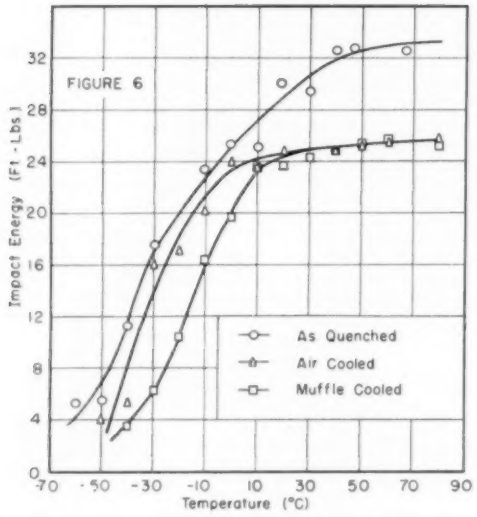


FIGURE 5

* For all temperatures up to 400° C. no difference in hardness was found if the specimens were air cooled rather than water quenched.



lower the temperature of brittle failure of such weldments. Further, it seems probable that the demonstrated beneficial effects of the low temperature stress relief advocated by Greene[6, 7] may well be due to overaging of the embrittled heat effect zone rather than to stress-relief alone.

QUENCH-AGING DURING SUB-CRITICAL COOLING OF HOT-ROLLED PLATES

The precipitation responsible for the quench-aging effects just described may be produced by quenching to a low temperature (e.g., room temperature) and aging or it may occur during cooling from the solution annealing temperature with cooling rates less than that which is attained in water quenching. In general, one would expect the effects of precipitation occurring during cooling to be less drastic than those obtained by quenching and aging at a low temperature. The effect of decreasing the cooling rate on the impact energy-temperature curves on the mild steel used in the quench-aging experiments is shown in Fig. 6. In an attempt to duplicate the cooling rate of a heavier plate, 48 specimens were hung in a sheet steel box, separated from each other by approximately $^1/_8$ in. This "muffle" was heated to 690°C. and allowed to cool in air. From the measured cooling rate at the center of the box of specimens, it is estimated that these specimens were cooled at a rate approximately the same as that which could be obtained at the center of a $^3/_4$-in. plate during air cooling. The upward shift in transition temperature corresponding to the decrease in cooling rate from "air-cooled" to "muffle-cooled" is of the same order as that observed when $^1/_2$-in. and $^3/_4$-in. plates from the same heat are compared.

ACKNOWLEDGMENTS

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Straightening Structural Members in Place

Results of a research project to study the underlying principles of methods used successfully in straightening damaged bridge members and effects on the metal of these methods

by Howard L. Harrison

INTRODUCTION

WHEN a steel bridge is damaged by a flood, fire or automobile wreck, the restoration of bent members becomes an urgent problem. It may be necessary to close the bridge to traffic until repairs are made. If straightening in place can be accomplished, there results a great saving in time and money over the alternative of fabricating a new member and substituting it for the damaged one.

Through the years, techniques have been developed for the straightening of bent members by the judicious application of heat, hammer blows, or transverse force, singly or in combination. Joseph Holt, of Seattle, has been a pioneer in the development and application of these techniques. His success in straightening damaged highway-bridge members led the Engineering Experiment Station of the University of Washington to sponsor a research project to study his methods, the underlying principles, and the effects on the metal in the members being straightened. The project was undertaken by the author, as a Research Fellow in the Experiment Station, with the cooperation of Mr. Holt.

This article is based upon the author's own experiments, and upon his observations of Mr. Holt's methods, supplemented by discussions with Mr. Holt. The author assumes full responsibility for all statements and opinions expressed herein.

THERMAL EXPANSION AND CONTRACTION

The essence of the straightening process is the proper application of localized heat. The basic principles of heat-straightening have been discussed in the literature[1, 2], but they warrant brief treatment here before a discussion of straightening procedures. Some pertinent facts about thermal expansion and contraction are illustrated by the following two hypothetical experiments.

First, consider a short steel bar whose temperature is raised 300° F. by uniform heating. Its dimensions increase by about 0.2% in all directions, if the piece is freely supported. No stresses are produced, if the heating is perfectly uniform. During cooling, the dimensions return to their original values, showing complete reversibility of the expansion.

Now, place the same bar between rigid blocks so that it cannot elongate when heated. When the temperature rises through the same 300° F., the bar tries to expand in all directions as before. Since the rigid blocks prevent the 0.2% elongation which would otherwise occur, they produce the same stress within the bar as if it were compressed 0.2% of its length. If the elastic limit of the steel were not exceeded, the compressive stress at the elevated temperature would be about 60,000 psi. However, ordinary mild steel yields much below that stress, and therefore incurs some permanent set by the time the temperature rise reaches 300° F. The lengthwise yielding causes a slight "upsetting" (permanent thickening) of the bar, in addition to the thermal expansion in the lateral directions. During cooling, the 0.2% contraction in all directions leaves the bar slightly shorter and thicker than it was in the beginning.

The heat-straightening method is based essentially upon restrained thermal expansion along an edge that needs to be shortened. Expansion, yielding and upsetting are caused by suitably localized heat application, after which the actual straightening is accomplished by the contraction that occurs during cooling.

STRAIGHTENING TECHNIQUES

When a structural member is bent, one edge of that member becomes longer than the other. If the two edges can again be made the same length, the straightening is accomplished. A member may be straightened by shortening the longer edge, by lengthening the shorter edge, or by a combination of both. Straightening by heating attacks the problem by shortening the longer edge. However, it is entirely possible to lengthen the shorter edge; this additional method of attack will be discussed also.

Howard L. Harrison is a design engineer with the Minneapolis-Honeywell Regulator Co., Minneapolis, Minn. While conducting the work reported herein, he was a graduate student in mechanical engineering, at the University of Washington.

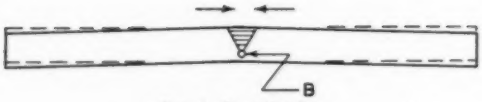

Fig. 1 Bent flat bar

As mentioned previously, the basic principle of the heat-straightening method is restrained thermal expansion of the metal causing an upsetting action. This upsetting action shortens the member in the heated area and upon cooling, contraction "pulls" the member back into line. Mr. Holt has summarized the method as follows: "The method of applying the heat must be such that the steel instead of expanding in length will upset, or expand into itself, so to speak. Also to make this method work there must be portions of the member cold enough, strong enough, and so situated as to force the metal to upset, or expand into itself, when and where heated unless some outside force can be added." In general, heat must be applied in such a manner that the member itself can furnish sufficient restraint to cause upsetting.

To illustrate the use of heat for straightening bent members, the straightening of an unrestrained member of simple cross-section will be discussed. A bent piece of flat bar is shown in Fig. 1. To straighten this member, an oxyacetylene torch is first applied at point *B;* heating at this point causes expansion in the immediate area. This expansion cannot cause much elongation of the bar because most of the bar is cold and resists such elongation. Thus the heated metal around point *B* upsets, once the yield point has been exceeded. At the temperatures (up to 1200° F.) used in straightening, the yield point of the metal in the heated area is considerably less than that of the cold bar. Having point *B* heated, the torch is used to heat the shaded area, working slowly from point *B* to the edge of the bar. As the torch moves toward the edge, upsetting occurs in the immediate area of heating. After cooling, the bar will have moved toward the straightened position shown by the dashed lines, the contraction being in the direction shown by the arrows. Further "heats" (heating-and-cooling cycles) will complete the straightening.

The purpose of the V-shaped heating area is to increase the upset proportionately from point *B* to the edge of the bar; point *B* acts somewhat like a hinge. According to Mr. Holt, by heating a V, most of the residual stresses caused by heating are relieved. Observations made by the author tend to verify this statement.

The use of a transverse force can frequently be of value when straightening with heat. By producing compression in that portion of the member which is to be heated, upsetting is facilitated. At the limit, all the thermal expansion goes into upset, if the external force stresses the steel to its yield point. Of course, the greater the upset per heat, the fewer are the heats required to accomplish straightening.

Mr. Holt introduced the author to the principle that steel under tension tends to yield to relieve that tension, if subjected to light hammer-peening in the tension area. This phenomenon has been separately investigated and reported upon by the author.[3] The principle is useful in straightening, being a means by which the shorter edge of a member can be lengthened. With the transverse force acting to provide compression along the longer edge of a bent member, the shorter edge, in tension, may be peened to speed the straightening.

The peening is done with the flat surface of a hammer, backed by a second hammer or sledge. Light blows are used; to casual observation, the peened surface is not marred. Note should be taken of the fact that the yielding of the steel appears only slightly due to the thinning action of the hammer blows.

If a member, in being bent, has upset in compression, the only way to straighten the member is to hammer out the thickened section, unless a permanently shortened member is acceptable. This type of peening will be sufficiently violent to work-harden the steel in the area involved, resulting in less desirable mechanical properties. However, if such an area is sufficiently heated afterward, one would expect the effects of work-hardening to be reduced.

Having discussed the basic straightening techniques, an illustration of their use in straightening a bent bridge member is in order. In 1949 the wooden decking burned on the Snake River Bridge near Pasco, Washington. As a result of the heat, many members of the bridge became severely warped. The Highway Department of the State of Washington engaged Mr. Holt to straighten 70 floor beams and two struts. With these members straight and with added support from below, the bridge could be made to handle one-way traffic until a new bridge was completed.

The floor beams for this bridge were built-up I-beams 28 in. deep and about 20 ft. long. Though an average of about 6 in. out of line, most of the beams responded well to heat alone, requiring no additional methods of attack for straightening. Not so for one of the struts.

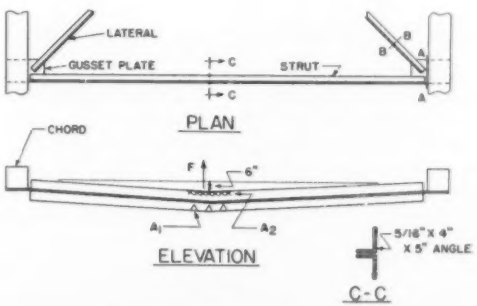

Fig. 2 Snake River Bridge strut

This member is shown in Fig. 2. Built up of two $^5/_{16}$- x 4- x 5-in. angles with the 4-in. legs together, the member was 6 in. out of line. The straightening of this member was made difficult because the gusset plates were bent considerably, and attached to them were laterals, all of which resisted the raising of the strut. Heat alone would not move the member; other means had to be employed.

First, a chain hoist was used to place a force on the member as shown by the arrow on the sketch. With this force in place, the area in which heats were to be made was subjected to compression; upsetting was enhanced. Heat was applied to areas similar to A_1 to cause a shortening of the longer edge of the strut.

Taking advantage of the area subjected to tension, light peening was applied to area A_2, speeding the straightening. Care was taken in applying heat and peening so that the straightened member would have its original length.

Because restraint existed at the ends of the strut, a second chain hoist was employed. This hoist was used as an aid in raising the bent gusset plates. One gusset plate was lifted at a time. With the lifting force in place, heat was applied along lines *A–A* and *B–B*. The reduction in yield point of the steel allowed a re-positioning of the strut ends.

Though discussed separately, the straightening of the strut and the lifting of the gusset plates were carried out simultaneously to produce the final result, a straightened member of unimpaired length.

EXPERIMENTS WITH MEMBERS UNDER LOAD

Of particular interest are the techniques to be used in straightening members which are parts of structures, and therefore carry loads. The most difficult straightening situation occurs when the bent member is loaded axially in compression. This condition can produce tension in the area in which heats are to be made. Upsetting is at a minimum because a part of the expansion goes to satisfy the tension. The usual V-pattern of heating is ineffective in areas of high tensile stress. Laboratory experiments were conducted on members under load, to determine more effective heating patterns to use when working with tension areas. Of course, one means of combatting tension areas is to make use of an external force.

A simple frame was arranged, such that a bent member could be loaded in axial compression by the tightening of two turnbuckles. The bending moment, produced by the axial load and the eccentricity due to the bend, creates (as well as a compression area) a tension area which must be heated in order to straighten the member. Using this simple arrangement, various heating patterns were studied.

Angles were used for the experiments because, due to the geometry of the cross section, they present more difficulties in straightening than do some of the other structural shapes.

A typical experiment proceeded as follows: A 40-in. length of $^1/_8$-x $1^1/_2$-x $1^1/_2$-in. angle was bent about 1 in. out of line using a hydraulic press. As much as possible, the bend was kept in the plane of one of the legs. The angle was then bolted to the frame and loaded in compression until out of line by an additional $^1/_8$ in. Under these conditions, the maximum tensile stress produced was estimated to be in excess of 20,000 psi. A dial gage was mounted in such a manner as to indicate the amount of straightening. With the setup complete, any heating pattern could be applied; its effectiveness was manifested by the change in readings of the dial gage.

Though many heating patterns were tried, three are typical of all. First, V-heats were used in the usual manner. Second, in the vicinity of the bend, the edge was heated; when cool, a second strip was heated, this time further in toward the heel of the angle. Third, the V-pattern was followed, but the heating was discontinued after about four-fifths of the way out along the V. The remaining portion of the V was heated separately after the first portion had cooled.

The usual V-pattern heats were not highly effective in producing straightening as should be expected. However, these heats seem to be able to relieve the residual stresses produced by the other heating patterns when improperly used. This fact will be discussed in connection with the other heating patterns.

In general, the greatest amount of straightening for a single heat can be accomplished by heating a portion of the longer edge of the member. By confining the heat to one edge, the remainder of the member is kept sufficiently cold to provide maximum restraint for upsetting. However, a high-tensile stress is left along the edge, and as a result, a second edge-heat will accomplish little or nothing, the expansion going to relieve the tension. The high-tensile stress must be relieved. A zone of compressive stress must balance the tensile stress; a heat in this zone causes upsetting which tends to relieve the edge tension. Thus the second heat is applied along a strip further in toward the heel of the angle. In practice, the author has never been able to relieve fully the tension produced by the first edge heat, and after several cycles of heating, the process failed to produce further straightening. However, the use of the usual V-heats allows sufficient plastic flow to equalize the residual stresses, and thus to restore the effectiveness of the edge-heat pattern.

The edge-heat pattern can be extremely dangerous when used to straighten a member under axial compression; this fact cannot be emphasized too strongly. The edge to be heated is the portion of the member carrying the highest tensile stress. A softening of this edge by heating may well reduce the load-carrying capacity of the member to the point of further deflection and failure. In the experiments, an effective edge-heat has reduced the deflection of the angle by almost $^1/_{10}$ in.; however, in one case where the axial load was high, an edge-heat caused the deflection to increase by

1/4 in. A similar situation occurring in a structure might well spell disaster.

The interrupted V-heating pattern seems to be the best technique for members under axial compression, from both the standpoints of effectiveness and consistency of results. In this system, the initially unheated portion of the V tends to go into compression because of the upset and contraction occurring in the heated portion. This tendency toward compression relieves the tension produced by the bending moment. When the outer portion of the V is heated, upsetting is favored in two ways. First, as just mentioned, the tendency toward compression exists here; and second, the heating is along the edge, a feature which is conducive to obtaining maximum restraint by keeping most of the member comparatively cold.

It should be noted that as the member straightens, the eccentricity is reduced, resulting in a smaller bending moment and smaller stresses imposed by bending. Thus, the usual V-heat is capable of finishing the straightening job once it is well under way.

About 265 separate heating-and-cooling cycles were employed during the period of experimentation. The temperatures reached during heating did not exceed 1400° F.; even at this temperature, the areas heated had a tendency to buckle slightly and form ripples.

SUGGESTIONS FOR STRAIGHTENING STRUCTURAL MEMBERS

For the straightening of a bent member carrying a load in a structure, the following suggestions are offered. These suggestions arise from discussions with Mr. Holt, observation of bridge-straightening operations, and the results of experimentation.

First: Before making any heats, the situation should be studied carefully. Of primary importance is the character of the load imposed on the member to be straightened. Knowing the character of the load will give an indication of the stresses existing in the areas which must be heated. As has been discussed before the tension produced by bending, in a bent member loaded in axial compression, may far overshadow the compression in the particular zone in which heats are to be made. In general, one might say that, in the early stages at least, a bent member in axial compression resists straightening while a bent member in axial tension aids the straightening.

Having determined the probable stresses in the member, attention should be turned to the expeditious use of external forces to produce an easier straightening situation. If a hoist is used to apply a force which pulls the member in the direction of its original alignment, a compressive stress is added to the existing stress picture in the area to be heated; the result is more upset per heat. Sometimes it is practical to use an external force to relieve the member of its load, making the member essentially free.

Second: With an attack planned and the external force in place, a cautious heat is in order. This heat serves as a check on the analysis of the situation; if the member responds well, the planned attack may be continued.

Third: In making heats, temperatures should be held below 1300° F. for a number of reasons. First, higher temperatures might soften the metal to the extent of yielding excessively under the imposed stresses. Second, cold metal for restraint is important for maximum upsetting; conducted heat should be held to a minimum. High temperatures require longer heating times and allow an additional conduction of heat. Third, high temperatures tend to cause ripples in the areas heated and, if nothing else, mar the appearance of the completed job.

A guide to keeping temperatures below 1300° F. is to keep the steel from appearing red in daylight.

Fourth: Hammer-peening is useful in two ways. First, a light peening will often cause yielding in a tension area. Second, heavy peening is necessary to remove the effects of upsetting occurring at the time of bending. This latter type of peening should be followed by heating to reduce the ill-effects of work-hardening.

Fifth: Not only must heats be made in the vicinity of the bend, but also at the ends of the member to allow it to regain its former alignment without affecting the remainder of the structure adversely.

Sixth: Probably the most expedient way to remove kinks from flanges is through the use of force, with little or no heating.

Seventh: The use of a piece of string is a handy means for determining the portions of a member that are out of line. From this information, heats may be placed strategically.

Eighth: The straightened member should be left with a minimum of residual stresses; the intelligent use of the "tools" of straightening will insure a relatively residual-stress-free member.

Ninth: Care must be exercised so that the straightened member will have its original length. A permanently shortened member is seldom structurally desirable.

The preceding suggestions are very conservative in some instances, and need not be followed with every straightening job. However, it must be remembered that the cost of a structure places a high premium on impatience.

TESTING PROGRAM

No one who has had occasion to see the results of Mr. Holt's work with structural members can doubt the potency of the straightening method. However, at times, the question has arisen concerning possible damage to the steel. A limited program of tests was run in an attempt to gain some indication of the change in mechanical properties brought about by the straightening process. The program included tension tests, hardness tests, impact tests, and the taking of photomicrographs. The material used was a 20-ft. section

Table 1—Allocation of Test Bars

Test use	Bar No. Standard	Bar No. Heated
Tension tests	6, 11	3, 8
Hardness tests	2, 7	4, 10
Impact tests	2, 7	1, 5, 12
Photomicrographs	2, 7	4, 10

of $^1/_4$-in. x 2-in. mild-steel flat bar. The flat bar was cut into 11 bars each 20 in. long; the allocation of these bars to the various phases of the testing program is shown in Table 1. The allocations were determined by lot in an attempt to get more representative results. "Standard" bars were those bars which were tested in their original state, serving as a basis for comparison; "heated" bars were those which were processed.

The bars used as standards for test results were set aside until the tests were run. The "heated" bars were bent edgewise and heat-straightened before testing. The bending was done in a special jig with the use of a hydraulic press. The bars were bent until $^1/_4$ in. out of line with the load removed. In straightening, at no time did the temperature of the steel exceed 1300° F.: for the most part, the temperatures were held below 1200° F. Tempilstiks were used for temperature determinations.

In the interest of economy of both time and money, the tests were designed to require the absolute minimum of machining on the test specimens. Though this feature of the testing program was not highly desirable, nevertheless it was felt that inasmuch as the tests were to be comparative in nature, some sacrifices to precision could be made without seriously affecting the results of the investigation.

Table 2 shows the results of the tension tests: the test bars were not machined, but were run in the "as-rolled" condition. There is no significant change in ultimate strength or in the point of yielding between "standard" and "heated" bars. The stress at which elongation increased rapidly with a uniform loading speed was tabulated for the "heated" bars. With a slight amount of plastic deformation, the characteristic yield point is lost.

Because the test bars were not machined, the position of fracture could not be controlled. The position of fracture is an important factor in total elongation. Thus, the percentage elongations of the bars vary somewhat. Fortunately three of the bars fractured in about the same position, and from these three, the "heated" bars show a loss in percentage elongation of about 3%. Some loss in elongation was to be expected because the straightened bars had a heavier cross section where upsetting had occurred. Machining of the bars would have given a more accurate picture.

The tension tests indicate little change in the mechanical properties determined by such a test. It should be noted that no fracture occurred in the heated zone of the "heated" bars.

Table 3—Results of Hardness Tests

Position before heating,	Rockwell B hardness Bar 4	Rockwell B hardness Bar 10	Position after heating	Rockwell B hardness Bar 4	Rockwell B hardness Bar 10
X 1′	82	82	1	82	81
2′	82	81	2	85	87
3′	86	80	3	85	85
4′	84	81	4	85	86
5′	84	84	5	84	86
6′	84	83	6	84	85
7′	87	84	7	85	84
8′	83	86	8	85	85
9′	83	82	9	85	85
10′	81	84	10	86	86
11′	82	83	11	86	85
12′	82	83	12	86	86
			13	84	83
			14	86	86
			15	88	87
			16	85	86
			17	85	84

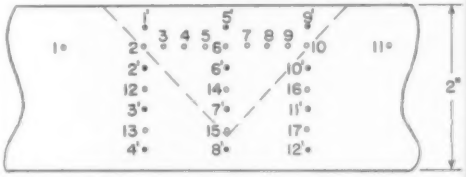

Fig. 3 Hardness reading positions

The results of the hardness tests are shown in Table 3. Rockwell B hardness readings were taken before and after straightening at the positions indicated in Fig. 3. The dashed lines show the outline of the heated zone of the straightened bar. A slight increase in hardness resulted from the straightening process, though not enough to be thought significant. Some increase was to be expected as a result of the plastic deformation.

The impact specimens for the Charpy tests were machined from the test bars as indicated in Fig. 4. These specimens were not standard in that one dimension was the $^1/_4$-in. as-rolled dimension of the flat bar, instead of the 0.40-in. dimension which is usual. Again

Table 2—Results of Tension Tests

Property	Bar 3*	Bar 8*	Bar 6	Bar 11
Ultimate strength	76,900 psi.	76,300 psi.	76,200 psi.	76,300 psi.
Point of rapid elongation	52,800 psi.	52,500 psi.	50,800 psi.†	51,300 psi.†
Per cent elongation	20.9%	19.9%	23.5%	27.0%
Position of fracture	$1^3/_4$ in. inside 8-in. gage length	1 in. inside 8-in. gage length	$1^3/_4$ in. inside 8-in. gage length	Center of 2-in. gage length

* Bent and straightened specimens.
† Actual yield point.

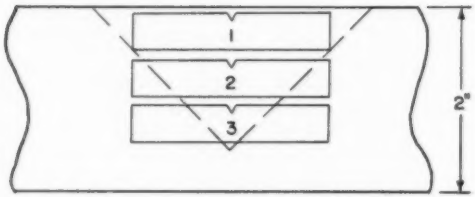

Fig. 4 Impact test specimen positions

in Fig. 4, the dashed lines show the outline of the heated zone of the straightened bar.

Table 4 gives the tabulation of test results. The "heated" specimens show energy absorption as good as, or better than, the "standard" specimens at the three temperatures used for the test. The specimens from the No. 1 position of the straightened bars show decided increases in energy absorption. This fact cannot be explained at this time.

Table 4—Results of Impact Tests

	Impact energy, ft.-lb.					
			Heated specimens			
			Values at Position			
Temp., °F.	Standard specimens Values	Av.	1	2	3	Av.
0	27		44	..	26	
	21		..	..	26	
		24				32
35	37		..	41	40	
	45		..	..	..	
		41				41
65	52		59	43	..	
	46		70	43	..	
	40		..	..	..	
	46		..	..	..	
		46				54

One means of defining the transition temperature between ductile and brittle fracture is that testing temperature at which the fracture shows half its area as ductile failure and the other half as brittle failure. Using this definition as a guide, the transition temperatures for both the "standard" specimens and the "heated" specimens were slightly above 35° F., that of the "heated" specimens being the higher of the two.

For photomicrographs, specimens were machined from the test bars as shown in Fig. 5, one specimen near the outer edge (No. 1 position) where most of the upsetting occurred, and the other near the neutral axis (No. 2 position) of the bar. The heavy line indicates the plane of the surface that was polished. In all, eight specimens were prepared. No observable difference in microstructure was noted between the "standard" and the "heated" specimens.

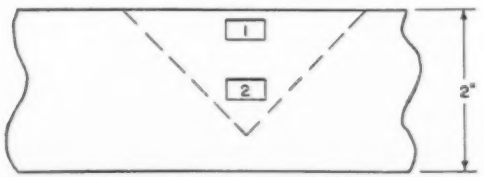

Fig. 5 Photomicrograph specimen positions

Fatigue tests might well serve as an indication as to whether or not damage is done to the surface of the steel by the high-temperature flame; some burning may take place during the heating. The American Railway Engineering Association's Bulletin No. 460 discusses the flame-shortening of eyebars to equalize the stress. In shortening an eyebar, a 12-in. length is heated to a temperature between 1600° F. and 1800° F. using an oxyacetylene torch. Then, the required upset is obtained by the use of a special clamp. After a series of tests, the conclusion reached was that flame-shortening has no appreciable effect on either fatigue or static strength.

Because of the limited nature of the testing program, no positive statements can be made regarding the effect of straightening with heat on the mechanical properties of mild steel. However, the consistency of test results appears to indicate that no significant changes occur in the steel.

CONCLUSION

The author has outlined some basic principles and current techniques involved in the straightening of structural members in place, and has described some relevant experiments which he personally conducted. The information presented is only fragmentary coverage of the subject, whose importance is perhaps best indicated by the marked success of Joseph Holt and others in the restoration of damaged steel bridges. The current techniques of straightening are highly effective when applied by an expert. However, inexpert attempts toward straightening a bent structural member under load could well be disastrous to the structure, as the result of unexpected deflections caused by heat application. Further research is desirable, toward a better and more widespread understanding of the behavior of metal members during straightening. Such research should be amply justified by its eventual contribution to the field of structural engineering.

ACKNOWLEDGMENTS

Appreciation is extended particularly to Mr. Joseph Holt, for his cooperation and untiring patience in explaining and demonstrating the straightening techniques he has developed and applied. The author is also indebted to the Engineering Experiment Station of the University of Washington for its sponsorship of his work, and to Professors B. D. Mills, G. S. Schaller and F. B. Farquharson, for their advice and assistance.

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Heat Flow in Welding

Heat dissipation calculations may be used for predicting size of weld and conversely inspection of ripples on finished weld indicates the heat input used

by A. A. Wells

SUMMARY

IT IS probably not generally realized that the solution for the heat dissipation by conduction from a moving point source on an infinite sheet, first given by Roberts in 1923, but usually associated with Rosenthal, may be used to calculate quite accurately the average melted width in single run butt welds in any material. A comparison is given with experiments conducted with steel by Jackson and Shrubsall, using automatic welding heads. The total heat supplied to make the weld is shown to fall asymptotically to twice that necessary to melt the weld nugget by itself, as the welding rate of heat input for unit thickness is raised indefinitely.

The Rosenthal solution also predicts the shape of the molten pool behind the heat source, hence the shape of the weld ripples. The inverse of this relation enables the approximate heat input and welding speed to be recognized by inspection of the weld ripples at any time after the weld has taken place. A long ripple lag denotes a high heat input weld and vice versa.

INTRODUCTION

The kinetics of most welding and flame cutting processes are governed primarily by the two factors (1) the heat generated at a concentrated source, by electric arc or contact resistance, or gaseous combustion (or, in the parallel process, oxygen cutting, by iron and oxygen combustion), and (2) by the heat dissipated through metallic conduction. The secondary heat dissipations by atmospheric convection and radiation may often be entirely neglected. For instance, the emission by radiation from a black body at 1500° C. is 6.5 cals./cm.^{2} sec., and at 1000° C. is 1.3 cal./cm.^{2} sec., and the heat transfer through a stagnant atmospheric layer 1 mm. thick for a temperature gradient of 10,000° C./cm. is only 0.5 cal./cm.^{2} sec., whereas the heat flow due to conduction may be some hundreds of times greater than this.

Some information is available on the heat inputs from the various sources, in relation to the measurable quantities, current voltage and power factor, and gaseous volumetric flows. For instance, Weck[1] has made a calorimetric study of the electric arc and finds that 90% of the electrical dissipation at the arc (taking power factor into account) is available as heat in the plate. Rosenthal[4] quotes a figure of 65%, neglecting power factor. An analysis of results given by Semper[5] shows that the efficiency of an oxygen cutting preheat flame, based on complete combustion of one of the two fuel gases, acetylene and oxygen (whichever is scarcer on a stoichiometric comparison), varies between 18 and 35%. Analogous results for welding flames do not appear to be available. It is hoped that a study of iron and oxygen combustion by the B.W.R.A. will soon yield results on the availability of heat from this type of source.

In classifying the various cases of heat dissipation by metallic conduction in welding, a first distinction may be made between suddenly applied sources of a constant rate of heat supply fixed in space, and moving sources such that steady temperatures are reached in the material at points fixed in space relative to the source (Table 1). The further distinction is then between cases which are essentially one, two or three dimensional, for sources consisting of planes, lines or points respectively in an infinite body. All the fundamental solutions are available.[2, 3, 4, 6] From these fundamental solutions the practical cases shown in Table 1 may be treated. In general, all the three dimensional practical cases must be dealt with by superimpositions of the fundamental solutions, as must the single run butt weld solutions for the limited case where the plate is narrow compared with the width of the fused zone.

The present paper is concerned only with the two dimensional case identified with the single run butt weld under steady weld deposition conditions. In order to simplify the treatment, the assumption is made that the melting is derived from the arc or flame source distributed uniformly through the thickness of the plate, so that the melted zone can be afterward

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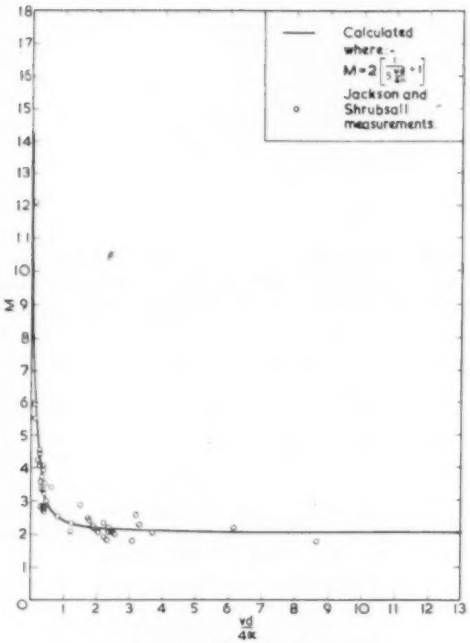

Fig. 1 Butt welding heat dissipation

recognized as a rectangular prism. The justification for this rather sweeping assumption will later be seen in the comparison with experiments. The further assumption is made that the presence of a narrow parallel air gap between the two plates, either before or behind the heat source (welding or cutting respectively) does not materially influence the heat conduction from the source.

THEORY

Heat Dissipation by Conduction

The problem of the temperature distribution t, above some fixed ambient value, at radius r in a wide plate of uniform thickness, with no surface losses, from a line source supplying q units of heat per unit thickness, and moving at uniform velocity v, has been solved by Rosenthal.[4] It is given by:

$$t = \frac{q}{2\pi k} e^{-(v\xi/2\alpha)} K_0\left(\frac{vr}{2\alpha}\right) \qquad (1)$$

The moving coordinate center is the line source, and ξ is then the component distance of any point from the source in the direction of motion, positive distances being measured in the direction of motion. k is the thermal conductivity of the metal, α the thermal diffusivity, defined as $k/\rho c$, where ρ and c are the density and specific heat respectively. K_0 is the modified Bessel function of zero order, second kind: $(2/\pi)K_0$ is tabulated in Jahnke-Emde.[6] K_0 is infinite at zero

Table I—Heat Dissipation by Metallic Conduction

	Reference	*Dimensional* (1)	(2)	(3)
Fixed source: sudden application	Carslaw and Jaeger	Upset weld. Start of flash weld	Start of single-run butt weld	Spot weld. Start of multirun butt weld
Moving source	Rosenthal	Flash weld. Welding electrode	Single-run butt weld	Multirun butt weld. Seam weld

value of the argument, and quickly approaches zero as this increases. Thus, for a true line source an infinite temperature must be maintained there; in practice, for a source with given value q, the remote temperature distribution may be independent of the purely local distribution of the source.

In order to find the melted width d, the maximum width of an isotherm T, which corresponds to the melting point of the material, can be determined. The assumption then implied is that the change of state at melting is unaccompanied by significant latent heat absorption or change of the value of α. Again, the justification for this assumption must rest with the appeal to experiment. At the widest point $\partial \sqrt{r^2 - \xi^2}/\partial\xi = 0$, so that, from Equation 1:

$$\frac{\xi}{r} = \frac{\partial r}{\partial \xi} = \frac{K_0\left(\frac{vr}{2\alpha}\right)}{K_1\left(\frac{vr}{2\alpha}\right)} \qquad (2)$$

where $K_1(\ ) = \partial K_0(\ )/\partial(\ )$, again tabulated in Jahnke-Emde. It thus follows from Equations 1 and 2 that:

$$q = 2\pi k T \frac{e^{-\frac{vr}{2\alpha}\cdot\frac{K_0(vr/2\alpha)}{K_1(vr/2\alpha)}}}{K_0\left(\frac{vr}{2\alpha}\right)} \qquad (3a)$$

and

$$\frac{vd}{4\alpha} = \frac{vr}{2\alpha}\sqrt{1 - \left(\frac{K_0\left(\frac{vr}{2\alpha}\right)}{K_1\left(\frac{vr}{2\alpha}\right)}\right)^2} \qquad (3b)$$

Both q and $vd/4\alpha$ depend primarily on $vr/2\alpha$, so that $vd/4\alpha$ can be plotted directly against q.

An important step now is to define the ratio:

$$M = \frac{q}{vd\rho cT} \qquad (4)$$

where $vd\rho cT$ is the heat which would be supplied simply to melt the width d of plate at the same speed without other losses. It can then be proved that:

$$M = \frac{e^{-\frac{vr}{2\alpha}\cdot\frac{K_0(vr/2\alpha)}{K_1(vr/2\alpha)}}}{\frac{vr}{2\alpha}\cdot\frac{2}{\pi}K_0\left(\frac{vr}{2\alpha}\right)\sqrt{1 - \left(\frac{K_0\left(\frac{vr}{2\alpha}\right)}{K_1\left(\frac{vr}{2\alpha}\right)}\right)^2}} \qquad (5)$$

When $vd/4\alpha$ is small this reduces to:

$$M = \frac{1}{\frac{vd}{4\alpha}\cdot\frac{2}{\pi}K_0\left(\frac{vd}{4\alpha}\right)} \qquad (6a)$$

and when large to:

$$M = \sqrt{\frac{\pi e}{2}} \qquad (6b)$$

Since Equation 5 is only indirectly related through Equation 3b with $vd/4\alpha$ it is convenient that there is a simple approximation, valid to $\sim 6\% + 1\%$ when $0.1 < \frac{vd}{4\alpha} < \infty$. It is:

$$M = 2\left(\frac{1}{5(vd/4\alpha)} + 1\right) \qquad (7a)$$

or

$$q = 8kT\left(\frac{1}{5} + \frac{vd}{4\alpha}\right) \qquad (7b)$$

The approximation is indistinguishable from the exact solution given in Fig. 1.* Equation 7b indicates an apparent threshold for q, below which no melting seems to occur at all, and Equation 7a, that the most economical use of heat in welding, for a given melted width, is to use a high heat input and speed of welding.

For steel, the lower limit for most economical heat energy input appears to be about 2400 cal./sec. cm., 10 kw./cm. thickness, and the threshold 240 cal./sec. cm., 1 kw./cm.

In Fig. 2, values of vd, calculated from Equation 7b for a number of metals in common use in welding, are plotted against heat inputs q. The calculations employ accepted values of α and T for each metal.

Rate of Electrode Melting

There is a further point, concerning electric arc welding only, worthy of mention at this stage. It follows from an experimental observation of Jackson and Shrubsall that "the energy utilized in melting the electrode for both coated and Unionmelt welding for all current levels is approximately 15% of the total energy input."

If it is supposed that this melted material is all transferred across the arc exactly to fill an initial gap D between the plate edges being joined, we have:

$$\frac{3}{20}q = vD\rho cT$$

or

$$q = \frac{20}{3}\cdot 4kT\cdot\frac{vD}{4\alpha} \qquad (8)$$

analogous to Equation 7b. The two equations are plotted in Fig. 3 for steel in which $4\alpha = 0.33$ cm.^{2}/sec. It now appears that for an initial average separation of the plates D, at a given energy level q, there is only one welding speed which will just allow a flush weld bead to be laid down. At other speeds the bead is either convex or concave. A lower energy limit of 360 cal./sec. cm., 1.5 kw./cm. now appears, below which only a convex bead can be laid down.

Weld Ripples

The remaining point concerns the shape of the molten

* A similar theoretical curve has been found in the Russian Reference 8.

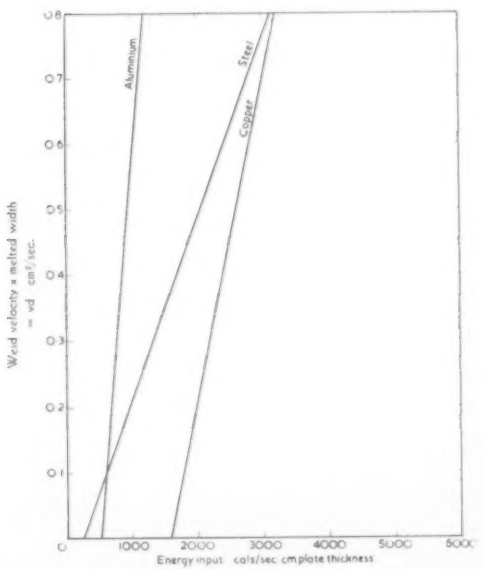

Fig. 2 Theoretical weld variables for different materials

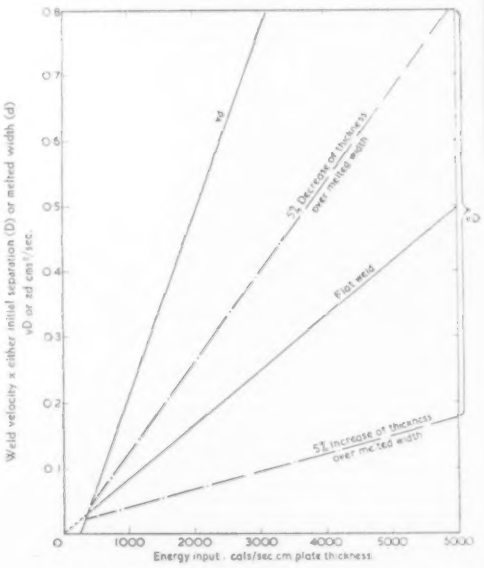

Fig. 3 Effect of electrode melting

pool, bounded by the T isotherm, behind the source of heat. It is of interest because the fluctuations of heat source intensity cause frequent small variations in the level of the molten pool which solidify at the rear to form the familiar weld ripples.

The maximum lag ξ_2 of the T isotherm behind the source must be given by the equation:

$$q = 2\pi kT \frac{e^{v\xi_2/2\alpha}}{K_0(v\xi_2/2\alpha)} \qquad (9)$$

From Equations 2, 3a, 3b and 9 the required ripple lag ratio $(\xi_2 - \xi)/d$ may be calculated indirectly for each value of q and $vd/4\alpha$, by first assuming specific values of $vr/2\alpha$ and $v\xi_2/2\alpha$. The ripple lag ratio is plotted against $vd/4\alpha$ in Fig. 4. For low heat inputs the ripples appear to be semi-circular, while for high inputs corresponding with maximum economy of energy, the ripple lag is greater than three melted widths.

EXPERIMENTAL VERIFICATION

Jackson and Shrubsall[7] have published the results of full experimental measurements on 43 automatic single run arc butt welds on mild steel, and these have been used to check the validity of the analysis presented above, and particularly that of Equation 7a. The continuous measurements which they made were of: arc voltage, arc current, welding speed and electrode rate of feed. Plate thicknesses ranged from 0.20 to 5.08 cm. and welding currents from 125 to 2100 amp. Sections across the welds were afterward made in order to measure the fused cross-sectional areas in each case.

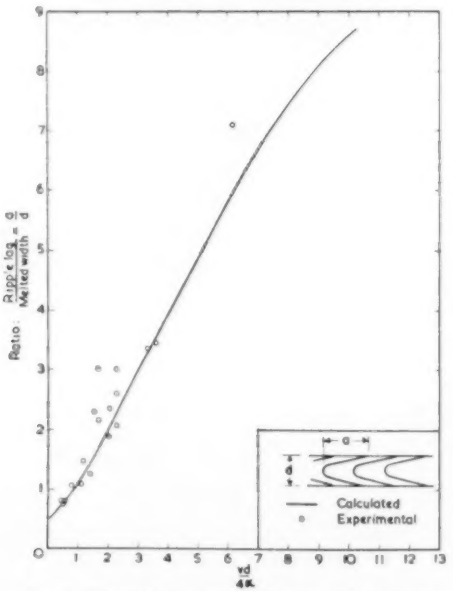

Fig. 4 Estimation of variables from weld ripples

From the experiments it has therefore been possible to determine the heat input per unit thickness, q cal./sec. cm., and the average melted width, d cm., assuming a flat weld bead. From these results M (Equation 7a) has been determined using a figure of 1820 cal./cc. as the heat of melting for steel. The values are plotted against $vd/4\alpha$, where $\alpha = 0.082$ cgs. unit, in Fig. 2. An efficiency of 75% has been assumed for the arc, whether d.c. or a.c. No power factor measurements are given for the comparatively few a.c. arc results. Agreement with the theoretical curve appears to be reasonable over the 75 fold variation of $vd/4\alpha$.

An attempt has been made to measure ripple lag ratios, in order to compare the results with the rate of heat input to a plate. In this case an automatic welding head was not available, so that weld beads were laid down by hand, at various welding currents, on mild steel plates from 0.127 to 0.343 cm. in thickness. With these thicknesses, melting occurred through the whole depth of plate, so that two-dimensional conditions were fairly simulated. Direct measurements of welding power were made by means of an indicating wattmeter. It was not found to be necessary to measure welding speed, as the ripple lag ratio, under steady conditions, is independent of this. The experimental results are plotted in Fig. 4 for comparison with the theoretical curve, and fair agreement between the two is seen for the limited range of heat inputs which were possible. A further point has been added in Fig. 4 for a high rate of heat input Unionmelt weld on $^3/_8$-in. steel plate. In plotting the experimental results, an arc efficiency of 75% was used, this having been determined for similar welding conditions by means of an auxiliary calorimeter test.

CONCLUSIONS

The main conclusions from the combined theoretical analysis and experimental verification of the heat flow in single pass arc butt welding, under constant conditions, are as follows:

1. That the two most important factors in the heat flow are the heat generation by the arc and the efficiency with which it is transferred to the plate, and the dissipation by metallic conduction. Other heat losses appear to be small in comparison.

2. That the total heat per unit plate thickness necessary to make a weld under the above conditions may be expressed in terms of that necessary to melt the fused zone, without losses, multiplied by a factor, which depends only upon the non-dimensional parameter $vd/4\alpha$. v is the weld velocity, d the average fused zone width and α the thermal diffusivity of the parent material. The multiplying factor is large for low values of $vd/4\alpha$, and tends to 2.07 when $vd/4\alpha > 2$. The complex exact relation for the heat input to the weld may then be closely approximated by a simple expression:

$$q = 8kT\left(\frac{1}{5} + \frac{vd}{4\alpha}\right)$$

where q is the heat input for unit thickness, k the thermal conductivity and T the melting temperature above the surroundings.

3. That the requisite initial gap between the plates welded may also be calculated so that the final weld is just flush with the plate, if a combined filler rod and electrode are being used.

4. That, under constant conditions, the shape of the weld ripples, when examined after solidification has taken place, may be used to show the conditions of velocity and heat input rate, at which the weld was made. For high heat input rates and velocities long weld ripples appear, and vice versa.

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World's Largest Universal Testing Machine to Be Built at Lehigh University

The world's largest vertical universal testing machine is to be installed in a new building to adjoin historic Fritz Laboratory on the Lehigh University campus, Bethlehem, Pa., Dr. Martin D. Whitaker, president of the university, announced recently. Total cost of new equipment and building to be ready for the opening of the academic year starting September 1954 is estimated at approximately $1,200,000.

In announcing the new plans to make the Fritz Engineering Laboratory testing center the most complete in the nation, President Whitaker said that the new installation will be made in cooperation with the Bethlehem Steel Co.

In making public the plans, approved by the university's board of trustees, Dr. Whitaker said, "The purpose of a structural testing laboratory at a university is to expand knowledge of the properties of engineering materials and of the behavior of engineering structures and to train personnel for positions in the structural and allied industries. This new testing center will furnish special testing facilities not now available to separate companies or engineering research investigation groups as well as provide for more varied student demonstrations."

The new building will house a 5,000,000-lb. capacity hydraulic tension-compression machine to be constructed at an estimated cost of $400,000, accessory equipment valued at $300,000 and modern laboratories which will widen the scope of testing in every field.

Primary responsibility for the design and supervision of the construction and installation of the machine will be shared by representatives of the Bethlehem Steel Co., representatives of the Baldwin-Lima-Hamilton Corp., Philadelphia; and Professor William J. Eney, head of the department of civil engineering and mechanics and director of the Fritz Engineering Laboratory at Lehigh University.

They will be assisted by Lynn S. Beedle, assistant director of Fritz Laboratory; Samuel J. Errera, engineer of tests at the laboratory; and staff members of the department of civil engineering and mechanics at Lehigh University.

Commenting on the facilities to be offered by the new laboratory center, Jonathan Jones, chief engineer of fabricated steel construction of the Bethlehem Steel Co., said, "The research possibilities offered by equipment of such proportions will be of inestimable value to fabricators, engineers and to the general public. The steel, cement and other heavy manufacturing industries will find here the means of testing to destruction the huge columns and girders basic to modern structures. Resulting modification in design could maintain high safety factors while reducing weight and cost appreciably."

"The 5,000,000-lb. capacity machine, serviced by a 20-ton crane, together with auxiliary apparatus, will make possible a vast expansion in the services heretofore offered industry of the East Coast in proof testing their products," said Professor Eney.

Hereafter, many new tests will be possible not only for industry but as a part of student demonstration and sponsored research investigation. It is expected that industry, specification writing boards and engineering society research committees over the entire nation will make use of these facilities not now available to them.

Tests which engineers are expected to bring to the laboratory from industry will include all kinds of materials including concrete cylinders and blocks, aluminum and magnesium castings, fabricated steel, oil well shafts, wood and wire rope.

An important detail will be the special anchoring floor and lateral supports for tests on large units which will not fit into the machine or require load application such as those which occur during windstorms, explosions and earthquakes. This will also make it possible to apply additional vertical or lateral loads to plate girders when tested in the 5,000,000-lb machine.

Auxiliary machines, in small laboratories to be provided, will permit extensive studies on the effect of repeated and dynamic loads which often cause failure through the fatigue of the material. The laboratory now has a torsion machine of 2,000,000 in.-lb. capacity, the largest in the United States, which is in current use in developing information for the structural engineer. The scope of these studies will be extended when new fatigue torsion machines are added to the new laboratory center.

New records in size and load capacity on many types of structures will be possible when the new tension-compression machine is in operation in what is planned to be the most complete civil engineering testing laboratory among the nation's universities and colleges.

At the present time only two 5,000,000-lb. machines approaching the Lehigh machine are in operation. Both are Government owned. One is located at the Philadelphia Naval Base; the other is at the United States Bureau of Reclamation in Denver, Colo.

Melting Rate of Coated Electrodes

The melting rate of coated electrodes is affected by several factors. Each of these factors is considered and discussed in detail

by J. ter Berg and A. Larigaldie

INTRODUCTION

UNLIKE carbon arcs and low-pressure metal arcs, the normal welding arcs have not often been subject to study.

The reason for this is the complex behavior of such an arc with respect to, for instance, the transfer of molten metal and the gas stream developed by wire or coating.

The weight of metal melted down during arc welding is one of the basic elements determining the economic value of the process.

In practice, we see that the joining of two or more parts into a single one can be accomplished in two different ways: first, the edge of each part can be partially melted and joined without any mixing with the electrode material; second, the bead can be formed only by the fusion of the electrode core, the overheating of the parent metal being just enough to assure a good joint.

An example of the first case is given by the carbon-arc welding process in which the burning rate of the carbon rod is low and can even be reduced by the use of shielding flux to protect the arc in such a way that the burning of 1 mm. out of a 6-mm. diameter rod can furnish a seam several meters long.

An even lower electrode consumption is obtained in inert-gas metal-arc welding using a tungsten electrode, shielding then being done by argon or helium.

In the second case (hard facing, for instance) the properties and chemical composition of the filler metal must be different from that of the parent metal; a shallow penetration of the weld bead and a low dilution of the base plate in the deposited rod metal is desirable. A new method fulfilling these conditions has been lately described with two arcs in series.[1]

Between these two opposite cases, we find the range of coated electrodes for common use, the burning rate of which varies between limits fixed by the conditions of application and the quality to be obtained. The possible speed of the work and the economy of said process are dependent on the quantity of melted metal that can be deposited in a given time. These considerations led us to seek out the elements involved in the melting rate of electrodes. These factors could be listed as follows:

1. Arc length.
2. Arc power.
3. Angle of rod with horizontal plane.
4. Diameter of the wire.
5. Melting point of the core metal.
6. Temperature of the wire.
7. Coating's thickness.
8. Chemical composition of coating.
9. Polarity of current.

EXPERIMENTAL EQUIPMENT

In the course of arc welding, the arc voltage, for instance, is subject to large fluctuations caused by the speedy movement of the gas stream and the agitation of the pool of molten metal. The transfer of metal drops through the arc can modify the arc voltage from 0 to twice the mean value when the passage of a drop would establish two arcs in series. Additional variation of the arc voltage is also due to irregular moving of the rod while hand welding or to the inertia and rubbing phenomena of mechanical parts in automatic machines.

The above considerations led to the conclusion, regarding the difficult measurements of the voltage, current and even power, that a method to integrate their value as a function of time may be preferred.

The most direct method seems to be a recording of these values as a function of time and to planimeter the resultant curve. Experience has shown, however, that this leads to uncertain results, due to the rapid arc fluctuations, which cannot be registered by the recording meter, and consequently a badly defined curve. Moreover, this method is relatively slow and is not suited to repetition of the experiment.

Said difficulties led us to use integrating meters of the O.K. type for the registration of the current and voltage and a Thomson watt-hour meter for the power.

Owing to the simplicity and speed of this method, mean value can be obtained based on a large number of measurements.

The apparatus' precision is plainly satisfactory; the manufacturers generally guarantee a precision of 1 to 2%. It is possible to improve it by way of control of the pressure of the brushes on the collector and after a test of the train of wheels. Of course, the meters must be calibrated on a duration similar to that of the measurements to be made.

To avoid the volt-hour meter's rotation before starting an arc and after an extinction, a relay adjusted on a voltage slightly over normal arc voltage cuts this meter circuit when this voltage exceeds said value. An electric stop watch inserted in the same circuit gives automatically the time during which the arc has been established. The circuits of these various meters are shown schematically in Fig. 1.

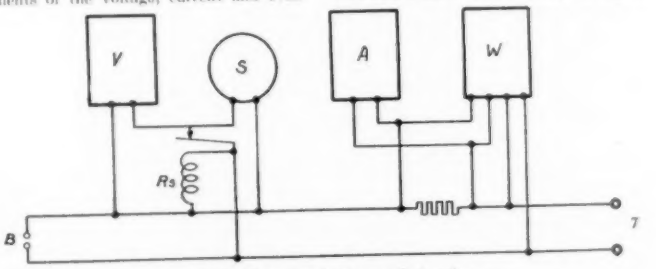

Fig. 1 Scheme of the used circuit

V = Volt-hour meter. *W* = Watt-hour meter. *T* = Welding rectifier. *A* = Ampere-hour meter. *S* = Stop watch. *Rs* = Relay. *B* = Arc

J. ter Berg and A. Larigaldie are connected with the S. A. Philips Eclairage & Radio, Paris.

The system operates without any manual intervention. The operator has to read, after the burning of a rod, the figures registered on four dials to obtain, besides the time of welding, the average value of power, voltage and current.

EXPERIMENTAL RESULTS

Definition of the Term Melting Rate: It is known that for a given type of electrode and a fixed polarity the weight P of metal deposited during a welding operation can be represented by the following formula:

$$P = (aI + b)t^*$$

where

I = welding current.
t = time of welding.
a and b = constants.

In each case examined, b always seemed very small compared to aI. Thus disregarding b the formula is:

$$P = aIt$$

Let P be in milligrams, I in amperes and t in seconds, then:

$$a = \frac{P}{It}$$

and is a constant value corresponding to the weight in milligrams of deposited metal per ampere per second and can be considered as the *specific melting rate.*

If, on the other hand, the weight of metal deposited per second is indicated as the *melting rate* S, we have

$$S_a' = \frac{P}{t} = aI$$

It must be noted that this quantity does not have a constant value and varies with the welding current.

In practice, an important item is the *maximum melting rate:* $S_{max.} = aI_{max.}$, $I_{max.}$ being the highest current to be utilized in the case considered.

These considerations show that an electrode presenting a small coefficient a can have a high melting rate if $I_{max.}$ is high. So we see that the maximum melting rate of a bare wire is lower than that of the coated electrode notwithstanding the fact that the specific melting rate of the bare wire is much higher.

Arc Length

The length of the arc has practically no effect on the specific melting rate. While testing, it has been noticed that an extension of the arc involving an increased voltage of 30% leads to a variation of a of less than 2% (see Fig. 2).

Similar results were obtained by Larson[2] refuting the hypothesis that the transfer of metal only occurs during the short-circuit period. The independence of the specific melting rate from the length of the arc can be explained by stating that an extension

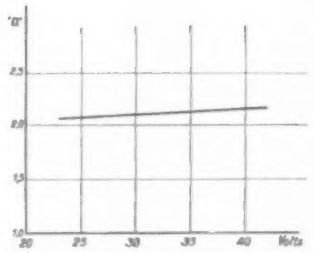

Fig. 2 Arc voltage versus specific melting rate

of the arc only increases the voltage drop across the positive column, where the energy produced does not contribute to the melting of the electrode.

Yet the potential drop and gradient along the positive column of arc are of a certain interest. Measurements have been made by Suits[3] for low-current arcs for different pressures and various gases by the method of vibrating electrode.

These measurements have been repeated with a modified technique especially designed for the study of welding arcs. Since the details of this work do not pertain to the subject on hand, it may be briefly stated that the potential gradient depends to a large extent upon the nature of the coating and of its chemical components.

Power Absorbed by the Arc

The preceding result shows that the power produced in the arc has no effect on the specific melting rate. Referring to Fig. 2, we see that for the same value of I (100 amp.) the variation of power of 2500 to 4000 w., due to increase of voltage, has practically no influence on the specific melting rates.

In an article of Rapatz and Hummitzsch,[4] the authors introduce the weight of deposited metal per kilowatt-hour as "Abschmelzaequivalent."

This quantity, however, is not well fitted to define the melting rate; we saw, indeed, that the arc's length, which is practically indeterminable especially in the case of coated electrodes, has a great influence on the energy input without a notable change of the weight of deposited metal per time unit.

Angle of the Electrode to Horizontal Plane

It was also found that the position of the electrode does not affect the specific melting rate. Even in overhead welding with coated electrodes the coefficient a is practically unchanged, proving that the force of gravity has no effect on this determination.

Diameter of Wire

The specific melting rate increases with the diameter of the wire. This rule seems to have a general value and can be observed either with bare wire or coated electrodes. The following table summarizes measurements made with bare electrodes and wire slightly coated with calcium carbonate:

Diam., mm.	*a pole +*	*a pole −*
Bare wire		
3.25	3.2	3.0
5	3.8	3.6
8	4.2	4.0
Coated wire		
3.25	3.1	2.1
5	3.6	2.5
8	4.1	2.9

Specifications issued by electrode manufacturers show that the welding current to be used for different diameters of the same type is approximately in proportion to the diameter of the wire; coefficient a also increasing, $S_{max.}$ will generally increase at a faster rate than this diameter.

The increase of a does not seem to be quite explained by the decrease of losses due to convection, conduction and radiation; it is also affected by the temperature of the melted drops.

In a study relative to direct current welding arcs with bare electrodes, T. Hehenkamp[5] found the following relation between the weight of the drops and the diameter of the rod:

Diameter of wire, mm.	*Weight of drops, mg.*
2.5	0.22
4	0.45
5	0.51
6	0.60

Current 100 amp. Pole +

The table shows that the weight of the drops does not vary as the square of the diameter of the rod; consequently the length of the drops must decrease. Supposing that the drops separated from the core according to a surface of constant temperature close to the melting point of steel, it is clear that the mean temperature of the drop will decrease with the length and, therefore, with an increase of the wire diameter.

Quantitative consideration by using the equation of the heat flow along the electrode as analyzed by von Engel[6] should lead to the same conclusion.

In any case, we see that the lowering of the temperature drop with an increase in core diameter can explain the increase of the specific melting rate found in the preceding table.

Attention must be drawn to the fact that this phenomenon is found to be independent of the polarity, which seems to indicate that the surface of the anode and

* Application of this formula is only possible to currents near to those used in normal welding; a and b vary in case of low amperage or very high current.

cathode spot plays only a secondary part in the cases examined.

Chemical Composition of the Wire

The specific melting rate increases with the fusibility of the wire metal, other factors being unchanged.

This rule can be verified with steel electrodes having different per cent of carbon. The following values were obtained:

Carbon, %	*a*
0.01	2.5
0.1	3.5
1	5.0

Current 100 amp. Wire 4 mm. on pole −

The increasing carbon content of steel not only lowers the melting point, but the combustion of a portion of the carbon provides a supplement of heat that accelerates the melting rate, while the gaseous outlet due to carbon oxide formation contributes to the projection of smaller drops, with lower mean temperature.

In the same way, the materials acting on the superficial tension of the molten steel will change the value of the specific melting rate. Doan[7] found that the addition of a small cover of antimony on a bare electrode (which causes a shortening of the drop length) will increase the melting rate by 30% compared with a normal rod, current and arc length being unchanged.

Temperature of the Rod

The electrode temperature is one of the important factors interfering with the melting rate value. If it were possible to raise the temperature of the electrode, before welding, to a point approaching the melting temperature (and supposing the drop temperature does not exceed this point) the specific melting rate could be multiplied by almost 5, which is the ratio between the latent heat of the hot metal and its heat of fusion.

The high current generally used in welding involves a considerable heating of the electrode due to the Joule effect.

Plotting the temperature of an electrode (determined by means of a thermo-

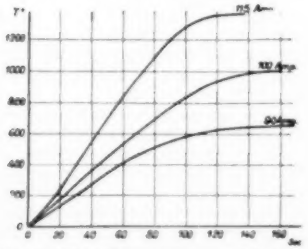

Fig. 3 Rise of temperature with time for different currents

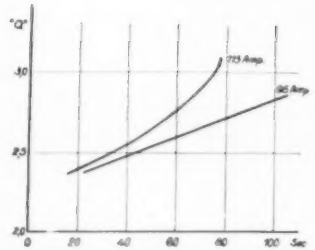

Fig. 4 Increase of the specific melting rate with time for two welding currents

couple) versus time for different currents, a bundle of curves is obtained (see Fig. 3). It shows that, for a normal melting time, a high current can lead to an exaggerated heating of the electrode.

If a welding current best suited for a given work has been found, preventing the overheating may limit the rod to a length shorter than usual. This is one of the reasons that led manufacturers to adopt a different length of wire for several types of electrodes. However we must bear in mind that the heating of the rod always increases the melting rate in the course of burning off the electrode (see Fig. 4) and special attention must be given to this item.*

Coating Thickness

As above mentioned, the highest value for *a* is obtained with bare wire. According to the characteristics of the coating, *a* decreases more or less with an increase in thickness (see Fig. 5).

Chemical Composition of Coating

Numerous tests have shown that certain elements of the coating have an effect on the specific melting rate, while others have little or no effect.

Experimenting with a coating of water-glass, 15%, ferro-manganese, 25% and

* For this reason, all measurements of melting rate must be done without perceptible heating, which is realized by shortening the time of welding or by decreasing the current, if necessary.

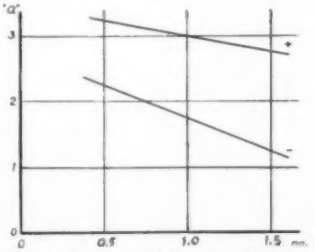

Fig. 5 Decrease of the specific melting rate on plus and minus with increasing coating. The wire used being 4 mm. in diameter, the coating thickness varies from 0.5 to 1.5 mm.

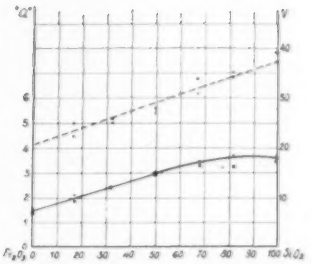

Fig. 6 Increase in specific melting rate and arc voltage with the silica content of the coating

iron oxide + silica, 60%, a variation of the ratio of the last components shows that the specific melting rate increases with the per cent of silica as shown in Fig. 6.

However, in the formula water-glass, 15%, silica, 35% and hausmannite + iron oxide, 50%, a variation of the ratio of iron oxide + hausmannite leaves *a* practically unchanged (see Fig. 7).

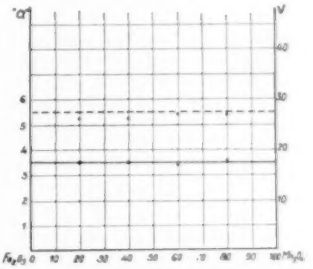

Fig. 7 Specific melting rate and arc voltage versus coating composition

Another experiment concerning a coating of water-glass, 10%, clay, 10% and, calcium carbonate + silica, 80% also shows that *a* increases with the relative ratio of silica. The following results were obtained:

SiO$_2$, %	*a*
0	2.2
20	3
80	4
100	5

The above-mentioned tests were made with 4-mm. diameter electrodes connected to the positive terminal.

*Effect of Polarity**

It is well known that with a carbon arc the consumption of the positive electrode is higher than the negative one. It was

* While this article was being written, Hummitzsch's work reported in a recent periodical[8] came to our knowledge; it seems, however, that our results do not agree on all points with those of Hummitzsch.

the general practice with carbon arc lamps to utilize rods of two sizes, the smaller one being connected to the negative.

The same phenomena is observed in metallic welding arcs. Some authors, Needham, for instance,[8] call attention to the fact that the melting rate is doubled with reversed polarity in the case of welding with bare electrodes. From a test with a 4-mm. diameter bare wire, involving the deposit of a continuous bead on a horizontal plate, the ratio was found to be near 1.3.

Different elements of the coating acting on the ionization potential of the arc atmosphere or the value of the work function will change the effect of the polarity on the coefficient a. In a preceding table, we have seen that the ratio between the specific melting rate in reverse and straight polarity was close to 1.5, a calcareous coating being used.

With most types of electrodes used in industry, we always found a ratio between 1 and 1.3; in one case, however, using an electrode with much quartz in the coating, we found a ratio which was even slightly smaller than unity.

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Dimensional Effects in Fracture

Discussion by Wendell P. Roop

This comment refers only to the effect of size on transition temperature. The most important conclusion in the paper is that increase in size does actually raise the transition, confirming results of work on wide plate specimens. The small amount of rise in the present data does not prevent the authors from concluding that the effect exists.

This conclusion, however, is linked with the idea that size effect is only a consequence of a similar effect of strain rate. Figure 5, in which transition temperature is plotted on deflection rate, shows a parallel shift with size such that in the larger specimens the transition is *lower* when the tests are made at equal deflection rates. However, when the deflection rates are proportioned to size, so as to produce equal strain rates in all sizes, the larger specimens show *higher* transitions.

This approach to the subject leads to an interesting conclusion about the effect of absolute strain rates. Figure 5 shows that in a slow test (deflection rate $^1/_{1000}$ in. per second to $^6/_{1000}$) the increase in size from 1 to 6 in. diameter would raise the transition by 7 degrees, whereas in a faster one ($^1/_{10}$ to $^6/_{10}$ in. per second) it would be raised by 17 degrees. This is consistent with the observation of greater size effects in notched than in unnotched specimens, at equal deflection rates.

Question: How is metallurgical identity assured in specimens of different thicknesses?

The use of a new specimen "at a slightly lower temperature to account for the cold working of the trial sample" is not understood. Table 2 seems to indicate that three 6-in. specimens were tested, each at a different deflection rate. Was each of these preceded by one or more trial samples? The authors state that the temperature in Table 2 is the highest at which "brittle fracture was experienced at the first trial," and this implies earlier trials not recorded. It is understood that this procedure is intended to eliminate strain-aging in intervals between successive loadings of the trial samples. But does it not rely on optimism about scatter? And on what is this optimism based?

The technique is ingenicus, but complete acceptance of the results awaits use of more and larger specimens.

The effect of strain rate on transition temperature in Fig. 5 is higher than in earlier work. A tenfold increase in rate shifts the transition upward about 40° F. However, since at low rates the effect is smaller, perhaps moderate differences in rate in "static" testing could be ignored.

The definite confirmation of the fact of size effect is of great importance, whatever its cause, since it makes all testing with small specimens too optimistic. Geometrically similar specimens of identical metallurgy and mode of testing show higher transitions as size is greater.

Wendell P. Roop, USN (Retired).

Paper by C. W. MacGregor and N. Grossman was published in The Welding Journal, **31** (1), Research Suppl., 20-s to 26-s.

Author's Reply

Based on their laboratory research, the authors discussed three specific topics in the general field of dimensional effects in fracture: (1) the influence of size on the transition temperature from ductile to brittle fracture, (2) the effect of various ratios of combined stresses on the brittle transition temperature and (3) the effect of combined stresses on fracture strength. Captain Roop's comments and questions are concerned with item (1) of the above together with the laboratory testing procedure and technique involved.

Captain Roop comments that "the most important conclusion in the paper is that increase in size does actually raise the transition." The authors do not believe that the amount of increase in the transition temperature found warrants this amount of emphasis and have stated in the Summary that ". . . the size effect for this material is of a trivial nature. . ." They also do not consider it correct to state that the ". . . size

effect is only a consequence of a similar effect of strain rate." The authors have made no attempt to dwell on the basic physical causes underlying size effect, but were content to confine their conclusions to the actual laboratory results. It should be reiterated, however, that it was necessary and important to distinguish between *deflection rate* and *effective strain rate* in order to arrive at a more rational basis for the evaluation of experimental data.

Captain Roop raises the question as to what precautions were taken to assure metallurgical identity of the different specimens. This can be answered by making reference to the paper under the heading of *Materials Tested and Specimens.* To quote from the paper, "in order to insure that the portions of the test specimens where fracture originates had the same strength and ductility level for all tests, the specimens were machined in such a way that the center of the specimen under the load coincided with the original axis of the $6^1/_2$-in. diameter bar supplied." This assured metallurgical identity since all specimens were machined in this way from a single billet where only slight variations could possibly exist in the axial directions.

Referring to testing procedure, several references were made in the paper to previous publications by the authors where this was described in great detail. The essential idea is that a freely supported and centrally loaded specimen is tested in slow bend at a constant temperature and deflection rate. An automatic load-deflection record is obtained of each test. The aim of the test is to secure a load-deflection curve (under a set of well-controlled conditions) which shows the inception of macroscopic plastic flow. Again quoting from the paper, "thus the results cited do not represent one single test but rather the limit of a number of successive approximations, with the finally satisfactory test value repeated two to three times. The accuracy of the temperature determination is ±3° F., that of the deflection rate ±5%. The amount of macroscopic flow may be judged from a previous study. . ." This quotation will probably answer Captain Roop's question concerning scatter. There was no scatter in the sense of conventional impact testing—which was evidently what Captain Roop had in mind. This will probably explain then one of the reasons why the authors have preferred this special slow-bend testing technique as contrasted to the conventional impact testing in their research studies. It should be emphasized, however, that they are not promulgating the slow-bend test as a replacement for the impact test. The Charpy impact test is a valuable commercial test which is satisfactory for many industrial requirements. The special slow bend test is a research method which, by utilizing well controlled variables, permits a more fundamental approach to the problem.

The authors feel that the use of larger specimens than those tested would not change the basic conclusions of the paper. Such tests would have to be conducted under well-controlled conditions and similar methods adopted as in the paper to assure metallurgical identity and mechanical similitude.

Copper in Stainless Steels

Copper in Stainless Steels, by Helmut Thielsch, published by the Welding Research Council as Bulletin No. 9 (August 1951). Price $1.00.

In recent years a considerable number of copper-bearing stainless-steel alloys have been developed and are now being produced commercially. Some of these special stainless steels are now extensively used in the form of castings and wrought products in many applications which require alloys high in corrosion resistance or alloys exhibiting age-hardening properties. In this report the author discusses in detail the physical, metallurgical and welding properties of many experimental and commercial copper-bearing stainless steels containing up to 30% Cr and between 0 and 35% Ni. The copper additions in most of the discussed alloys usually varied between 1 and 5%.

Among the topics covered are the phase relations, hot-working properties, corrosion resistance, age-hardening characteristics, effect of alloying elements such as Mn, Si, Mo, Cb, Ti, W, Be, V, stress-corrosion cracking, heat treatments, mechanical properties and weldability. In addition, detailed tables are given in which various American and foreign patented and commercial alloys are listed. The report represents a compendium of 166 references to published articles and patents as well as many unpublished contributions received from various research investigators in the United States and abroad.

Copies may be purchased through the American Welding Society, 33 W. 39th St., New York 18, N. Y.

Thermal Fatigue and Thermal Shock

Thermal Fatigue and Thermal Shock, by Helmut Thielsch, published by the Welding Research Council as Bulletin No. 10 (April 1952). Price $1.00.

The continuous improvement and development of many types of process equipment and machinery which, completely or partially, are exposed at elevated temperatures has resulted in an ever-increasing demand for engineering materials which can provide satisfactory service at higher and higher temperatures and pressures. Applications subject to thermal fatigue and shock may further increase the severity of the service requirements and, sometimes, may seriously reduce the life of a material. Thermal fatigue and shock denote the effects of temperature changes or alternating exposures at higher and lower temperatures. The changes may be cyclic and occur at regular intervals or they may occur at irregular intervals as, for example, in the occasional or repeated shutdown of equipment which ordinarily is operated at elevated temperatures.

Among the subjects are the characteristics of thermal fatigue and shock, effects of stresses, design, similar- and dissimilar-metal joints, structure, carbon migration, intergranular oxidation, phase transformations and welding. Examples of thermal fatigue and shock failures in various service applications are given and discussed. Finally, the more important and interesting testing procedure used to evaluate thermal fatigue and shock are described.

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